NAVAL POSTGRADUATE SCHOOL

Monterey, California

THE EVOLUTION OF NAVAL WARFARE TECHNOLOGY
AND THE IMPACT OF SPACE SYSTEMS

by

Patrick James Sharrett

September 1987

Thesis Advisor: Carl Jones

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

A186 400

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT approved for public release; distribution is unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Naval Postgraduate School 6b. OFFICE SYMBOL (If applicable) Code 72	7a. NAME OF MONITORING ORGANIZATION Naval Postgraduate School
6c. ADDRESS (City, State, and ZIP Code) Monterey, California 93943	7b. ADDRESS (City, State, and ZIP Code) Monterey, California 93943
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO / PROJECT NO / TASK NO. / WORK UNIT ACCESSION NO

11. TITLE (Include Security Classification)

THE EVOLUTION OF NAVAL WARFARE TECHNOLOGY AND THE IMPACT OF SPACE SYSTEMS

12. PERSONAL AUTHOR(S)

Sharrett, Patrick James

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Master's Thesis	FROM ____ TO ____	1987 September	178

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	naval history, naval warfare technology, space systems

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

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. increasing force endurance
. reduction of reaction and weapon delivery times
. reduction of exposure and risk to a force
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20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL Professor Carl Jones	22b. TELEPHONE (Include Area Code) (408) 626-2772 22c. OFFICE SYMBOL Code 74

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

19. Abstract cont.

emphasis on and support of space system development by the U.S. Navy is recommended.

Accession For	
NTIS GRA&I	☑
DTIC TAB	☐
Unannounced	☐
Justification	
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Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

The Evolution of Naval Warfare Technology and the Impact of Space Systems

by

Patrick James Sharrett
Lieutenant Commander, United States Navy
B.S., Southern Illinois University, 1974

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS TECHNOLOGY
(Space Systems Operations)

from the

NAVAL POSTGRADUATE SCHOOL
September 1987

Author: Patrick James Sharrett

Approved by: Carl Jones, Thesis Advisor

Roger Evered, Second Reader

Rudolf Panholzer, Chairman, Space Systems Academic Group

Gordon E. Schacher, Dean of Science and Engineering

ABSTRACT

This thesis traces the history of naval warfare technology from antiquity to modern times. By analyzing various technological innovations, including their development, assimilation, and employment by navies in battle, five basic naval warfare trends are identified to which technological changes have contributed. These trends are:

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I. INTRODUCTION

The ability to adapt to a changing environment is a characteristic which distinguishes between survival and extinction in animal species. It is this feature in human beings which has led to man's presumption of dominion over all other living things. For human organizations, the prospects of survival are similarly enhanced by the ability to adapt to new circumstances while still achieving their goals and purposes.

Military organizations, though not particularly noted for their adaptability to change, are established to ensure the survival of a state or government. In the course of history, as humankind's brawn has deferred to machine and brain, the means provided to military organizations to accomplish their purposes have often changed. When armies and navies have appropriately chosen and effectively used the new means, their chances of victory improved.

Generally, warfare is too complex to be altered in a short time by any single change. With the exception of nuclear weapons, no change in history has fundamentally altered the means or nature of warfare in the lifetime of a human being. But that situation is itself changing as a result of technology. For naval warfare, the direction of basic change is towards the relative importance of submarines and spacecraft compared to surface ships and aircraft.

The possibility of global nuclear war seems to set rational limits on the extent of future conflict, but warfare is hardly the result of rationality. It is the result of the quest for survival. As long as a nation or government perceives that its chances for survival are better without warring against another nation, then it will not engage in warfare against that nation. This is the logic of the concept of mutual assured destruction between the United States and the Soviet Union. However, the situation is much more baleful than that.

The Marxist-Leninist doctrine, which guides Soviet policies and actions, conceives of warfare as an on-going process of struggle between the forces of socialism and capitalism. The process may or may not involve armed conflict, but since armed conflict is a vehicle for gain in that struggle, it must be assiduously prepared for. If the net gains attainable through armed conflict are perceived to be significant enough, then that means may be used.

Technology is the sine qua non of socialist progress including the preparation for armed conflict. In this context however, "preparation" is not the short-term mobilization sort of activity with which Americans normally associate it. Rather, it is an on-going set of actions and behaviors which are sought to provide the Soviet military the necessary advantages either to use armed conflict as a means of gaining in the struggle or surviving, should armed conflict ensue.

Whether or not Soviet adulation of technology has caused or increased it, modern military organizations are inextricably linked to technological change. As the pace of change continues to accelerate, the probabilty of revolutionary effects grow.

This study looks at one aspect of technological change, that which affects naval warfare. Throughout history the means of naval warfare have undergone many evolutionary changes. Revolutionary change, when it occurred, was not immediately used for advantage in combat. Over time however, it so changed the means of naval warfare that it was in effect revolutionary. Since the difference between revolution and evolution is the rate at which the change occurs, technological progress has made all developments potentially revolutionary.

No endeavor by human beings has been as heavily technology dependent as the exploitation of space. No means of warfare is as technologically complex as naval warfare. Thus, the convergence of space systems and naval warfare on that basis alone is inescapably synergistic in its effects. Patterns in the history of naval warfare point to that convergance, as this study will show. The U. S. Navy must embrace that convergence as a matter of survival.

II. THE MEDITERRANEAN FROM ANTIQUITY TO THE MIDDLE AGES

A. THE EGYPTIANS

From the oldest records of civilization it is clear that littoral nations built watercraft for the transportation of people, raw materials and goods. It seems likely that the desire to protect these vessels from piracy provided the initial motivation for the construction of warships. The oldest pictorial evidence for a naval expenditure is an Egyptian bias-relief of about 2600 B.C. which shows vessels employed by the Pharaoh Sahure [Ref. 1: p.1]. Evidently built without keels, the ships have a rope truss stretched between the raised bow and stern. By tightening the truss with a simple tourniquet the vessels were given longitudinal strength and stiffness to match sea surface and loading conditions. Even the earliest ships had two modes of propulsion oars and sail. Rowers appear to have been the primary means but favorable weather permitted the use of the single square sail on a bipod mast.

About 1190 B.C. a naval battle occurred between the fleet of Ramses III and invaders known to the Egyptians as "the Sea People". The action is recorded on a temple wall at Medinet Habu and is the earliest extant picture of a naval battle [Ref. 2: p.13]. Certain innovations are apparent in the portrayal. The Egyptian warship is shown with no hogging truss, indicating that it was built with a keel. There appear to be high bulwarks along the sides of the vessel to protect the rowers. The ships of both sides are fitted with fighting tops on single masts, and an Egyptian warrior is clearly shown slinging a shot from one of them. A prow projecting from the stem of the Egyptian vessel terminated in a carved lion's head. Some observers claim that the projection is a ram, but others consider it too high above the water for such a purpose. Finally, the Egyptians are shown using grappling devices thrown from ropes as a means of drawing ships together, possibly for boarding or ramming. [Ref. 2: p. 197]

Although the portrayal described above is ancient, it could adequately describe naval battles which occurred during the next two thousand years. The appearance of multiple banks of rowers marks the next development in warships. Legend, conjecture and scanty bits of other evidence credit the Phoenicians with the first rams and the first warships with two rows of oars about 700 B.C. Herodotus describes a three-banked warship, a trireme, built by the Egyptians in 600 B.C. Many variations in the number of rowers and banks were tried, all apparently with the goal of increasing speed and endurance. Evidence indicates that the trireme became the primary war vessel in the eastern Mediterranean about 500 B.C. and so remained for the next several centuries.

B. THE GREEK TRIREME

The Athenians built perhaps the best triremes. Powered by 170 oars on three banks, they were capable of brief bursts of speeds up to ten knots. A trained crew could spin the trireme galley on its axis and go backwards or forwards with equal dexterity. At the bow was a ram or rostrum. In earlier ships the ram protruded above the waterline but experience proved that placing it below the surface made it more effective. Built in conjunction with strengthened bows, the hardwood ram was three-toothed spur sheathed in iron or bronze and projecting about ten feet forward of the bow. The middle tooth was the longest and sharpest, and was used to pierce the side of enemy ships. As the attacking vessel was propelled forward, the other two teeth of the ram caved in the sides of the enemy ship releasing the weight of the sinking vessel.

The Greeks employed tactics which took full advantage of the trireme's speed and maneuverability. After working up speed, they made a swift, close-to approach, shipping oars on the engaged side with a quick, spinning thrust. The opposing ship's oars, enmeshed in the synchronized threshing, broke off cleanly leaving the enemy vessel helpless. The Athenians then swung their ship around, regained speed and delivered their smashing ram-blows into the side of the immobile foe.

Sails were outfitted on the triremes permitting some wind aided cruising. Battle maneuvers however, called on oar power as the only reliable motive force. Catheads which projected horizontally from the sides of the trireme were added later. These structures came into contact with opponents oars during the approach and provided a quicker, surer means of breaking them. Boarding tactics led to generally chaotic engagements and were therefore employed only as a last resort.

1. The Battle of Salamis

The first decisive naval action in history was fought in 480 B.C. A combined Greek fleet of 366 triremes defeated a Persian fleet of at least twice that number. Using a portion of his fleet, the Greek commander Themistocles lured the large fleet of Xerxes into a narrow strait. The bottle neck presented a much smaller front to the Greeks and eliminated the numerical advantage of the larger force. The larger part of the Greek fleet then rushed from sheltered waters into the side of the nearly immobilized Persian fleet, smashing ships at will. In the wild melee which followed Xerxes lost at least 200 ships, the Greeks 40. The remainder of the Persian fleet retreated in disarray and the ships supporting Xerxes large land campaign were driven from the Mediterranean. The Persian king had to postpone his invasion of Greece by a year. The respite was sufficient for the cities of Greece to unite and assemble enough land forces to defeat Xerxes at the battle of Plataea, ending forever the menace of Persian domination. [Ref. 3: p. 12]

The battle of Salamis had major signification in world history, but what contributed to its outcome? The technology of the warfare was common to both sides. The fast oarpowered triremes had essentially comparable main batteries--the ram. The Greek ships each carried 20 to 25 hoplites serving as marines. Although the hoplites were more than a match for their Phoenician mercenary counterparts, the hand to hand combat occurred only after several tens of Persian ships had been sunk and the invading fleet stalled.

Though the striking power of the opposing forces, ship for ship, was basically equal, Themistocles had tactically arrayed his fleet so that a proportionately larger number of his weapons could be brought to bear. Consequently, he was able to deposit a greater amount of energy on his opponent, over a smaller time period, than his opponent could deposit on him. By pressing the attack often and quickly, the victors reduced the ability of their enemy to deposit their energy effectively. What Themistocles was able to achieve by tactics is also the story of naval warfare technology. It is the attempt to develop the means to deposit energy more selectively and efficiently over a greater distance, while concurrently reducing one's vulnerability to the enemy's reciprocal attempts.

C. ROME

The centuries after Salamis witnessed much combat but little in the way of new technology applied to naval warfare. Ships with four or five banks of oars replaced Grecian triremes, but the ram was still the main weapon. During the first Punic War (264-241 B.C.) a new naval power emerged in the Mediterranean. Rome, with it's history of successful land warfare, challenged the existing main naval power in the Mediterranean, Carthage.

1. The Corvus

Lacking naval experience and suspicious of their ability to master the complex maneuvering of a quinquereme in ramming tactics, the Romans took their vaunted army to sea. To the Romans, land combat techniques were the proven and effective means of applying the energy of warfare to the enemy. What they needed however, was a means to transport that energy from one vessel to another during battle. The corvus was invented to provide that means. A combination grappling and boarding ramp, the corvus was mounted on the prow of the Roman warships and served to channel their combat energy into enemy ships. To hold the main means of warfare, the Romans mounted fighting turrets on their galleys where soldiers would mass prior to dropping the corvus. The Romans essentially transferred the battlefield to ships.

The turrets and corvus took the Carthagenians by surprise. In the battle of Mylae (260 B.C.) Roman soldiers poured over into Hannibal's ships decimating the bewildered crews. Four years later at Ecnomus, the Romans again used their devices after successfully executing a breakout from an enveloping Carthagenian force. In the ensuing battle Carthage lost 60 ships to capture, 30 to ramming. Rome lost only 24. [Ref. 3: p. 16]

Simple but effective, the technology employed by the Romans permitted their commanders to use more familiar forms of combat energy in a new environment. In contrast, the Carthagenians were taken by surprise. Not expecting to see such methods employed at sea, their crews provided weak opposition to the Roman soldiers bearing their efficient short swords. The Carthagenian navy never developed a successful defense against the corvus and was subsequently replaced by Rome as the main Mediterranean naval power.

2. Waterline Protection

For at least a thousand years naval action had centered mainly on ramming tactics. Ships were designed and built with large projections, stout bulkheads, and the oar power necessary to drive home the point. Not until Marcus Agrippa built ships for his friend Octavian, were defensive measures designed and constructed into warships. By adding large beams to the planking on the waterline, Agrippa hoped to diminish the shocking blows of ramming. To this end he was successful and had conceived of the first "belt armor". [Ref. 3: p. 20]

In a later battle at Mylae (37 B.C.) Agrippa's larger, stronger ships defeated a group of faster, more maneuverable vessels under Sextus Pompey. The battle was indecisive for a time, but eventually the stronger ships, relatively immune to ramming, took their toll. Pompey lost 30 ships, Agrippa lost five. [Ref. 3, p. 20]

A year later fleets under Agrippa and Pompey engaged each other at the battle of Naulochus. Again the large, slower vessels of Agrippa faced a more mobile enemy.
To counter the elusive ships of Pompey, Agrippa developed and used a grappling projectile. With it, he pulled ships together from a long range. Once held together, Agrippa used his larger ships to push Pompey's ships onto the coast. What striking distance Agrippa could not gain by using grappling projectiles, he gained by using fire arrows. The modest increase in the range at which he could deposit energy led to victory. [Ref. 3: p. 21]

3. Emphasis On Speed - The Liburnian

Sometime during the middle of the first century B.C., a lighter, faster galley was introduced. Known as "liburnians" these vessels were adaptations of those used by the pirates who operated off the Illyrian coast [Ref. 1: p. 16]. Liburnians may have formed part of Caesar's fleet in the naval action in Quiberon Bay in 56 B.C. The battle was significant because it is the oldest recorded naval engagement in which oar powered ships opposed ships relying mainly on sails for power. The sailing ships were from the Veneti tribe of Brittany. Built mainly of oak, the northern ships were too stout to be badly damaged by ramming. So Caesar's force immobilized them by tearing away their rigging with grapples and hooks. [Ref. 1: p. 16]

In the battle of Actium (31 B.C.), Agrippa led a force of liburnian ships in a defeat of larger, conventional galleys under Antony and Cleopatra. Agrippa's vessels were faster and there were more of them. Using both assets to full advantage, Agrippa surrounded and burned the enemy ships, once again employing fire arrows. Actium is interesting because it shows Agrippa as having adopted a type of ship and means of employment completely opposite to what he used at Mylae and Naulochus. His victories are a tribute both to his tactical ability and to his understanding of the physical capabilities of his ships. He succeeded remarkably in what would become the age-old challenge of matching the appropriate tactics with the current technology to derive victory in combat.

D. GREEK FIRE

Between the appearance of the trireme and the battle of Lepanto 1571 A.D., only one weapon innovation had a significant impact on naval warfare. That innovation was "Greek fire". Invented by a Syrian architect who gave the formula to the Emperor Constantine Pogomatus, this early incendiary was mixture of sulphur, pitch, niter, petroleum, and probably quicklime [Ref. 4: p. 14]. The exact composition is somewhat conjectural because the formula was a Byzantine state secret for centuries and present day authorities differ on its composition [Ref. 5: p. 124].

Greek fire was first used in 673 A.D. during the Saracen naval and land expedition against Constantinople. The Moslem armada had forced the passage through the Dardanelles and came upon the defending Byzantine fleet. From the prows of the defending ships, protruded brazen tubes. When the Moslem ships got close enough, the tubes spewed forth jets of liquid fire. Clinging to whatever it struck, the incendiary burned fiercely. The hurried application of water only incited the flames' intensity. Arab ships and men were helpless. [Ref. 5: p. 124]

The delivery method was itself an ingenious means. The mixture was packed into brass bound, wooden tubes into which water was then forced at high pressure. As it exited the launch tube, the compound burst into flames and was projected a considerable distance by the force of its own explosion as well as the water pressure. After disastrous initial experience, the Moslems learned that sand, vinegar or urine were the only extinguishing agents [Ref. 5: p. 124]. However, the combination of outright destructiveness and sheer terror of Greek fire enabled the Byzantine fleet to retain a measure of maritime supremacy against the Moslem challenge. The walls of Constantinople were inviolate for the next six centuries.

E. SUMMARY AND TRENDS

For the first two millenia in which records of naval warfare exist, the means of waging battle at sea remained amazingly constant. In various combinations they involved ramming, boarding, and the use of fire transmitted by arrow, fireship, or Greek fire. Larger missile devices such as the trebuchet were commonly used in land warfare, particularly in siege operations. However, the inherent flimsiness and instability of warships as platforms, coupled with the evasive capability of relatively small targets made such contraptions risky and ineffective in naval warfare. There is no record of any naval action being influenced to any degree by missile throwing devices until the appearance of cannon.

The effective distance of decisive naval action thus remained the length of a ship. As the primary means as well as main conveyance of force delivery, the ship was the object of the most significant changes during this time period. The trends toward greater speed and maneuverability are unmistakable. In Rome's case however, where the primary weapon was the combat soldier, it comes as no surprise that the development of defensive protection was equally important. Consequently, sturdy ships which provided a good platform for sword wielding soldiers provided the advantage in the Punic Wars and in Roman civil conflicts.

Only Greek fire can be considered a truly innovative and decisive weapon. As the product of some vague alchemy it was the unique possession of one force and for several centuries its use offered a military advantage which kept its owners free from hostile domination. The method of application was ingenious and without parallel until the twentieth century. The range at which it was effective was probably nearly equal to a ship length. However, its employers did not have to subject their own vessel to reciprocal blows of anywhere near the same effectiveness. In practice then, it did provide a measure of range superiority.

With the exception of Greek fire, the role of surprise and superior tactics in victory was larger than any physical or technological advantage. The same theme will be seen again in the seventeenth and eighteenth centuries.

III. THE MIDDLE AGES TO THE SIXTEENTH CENTURY

The records of shipbuilding and warfare which cover the period from the seventh to the thirteenth century shed little light on the peculiarities of naval warfare. The basic galley which served the Greeks and Romans remained the primary war vessel of the Mediterranean countries until the eighteenth century [Ref. 6: pp. 570-571]. In northern Europe longships of the type associated with the Norseman were the primary war vessel until the early thirteenth century. The ships grew in size until they had sixty oars per side in a single row and were also fitted with a mast and square sail. Vessels of this type were used by William of Normandy to ferry his invasion force to Hastings in 1066 [Ref. 1: pp. 21-22]

Though the period covers a time of continuous conflict between English and French monarchs, there were no regular navies. Merchant ships travelled in convoys and were usually armed to deal with the chronic threat from pirates.

A. THE FIRST USE OF SAILING TACTICS

In order to keep costs down, merchant ship owners continually experimented with ways to eliminate the overhead expense of large rowing crews. Such experimentation led to improvements in sail as a significant motive power source. Unfortunately, precise times in history when sailing advances occurred are difficult to pinpoint prior to the sixteenth century. One advance which probably occurred during this time was the lateen sail. The lateen sail is essentially a square sail similar to those of the Mediterranean with the after end of the yard angled up and the forward edge of the sail shortened. The modification permitted the ship to sail closer to the wind direction permitting much wider range of use. [Ref. 6: p. 584]

The first description of the use of sailing tactics in a naval warfare involved the battle of Dover in 1217. A fleet of English sailing ships, of the Norse type, deliberately allowed the larger French fleet to pass. The English then turned and, with the wind advantage, bore down on the enemy. Although the tactic and means to give the advantage were novel at the time, the conduct of the warfare was not. Sanderson describes the action:

> The fight raged around the great (French) ship of Eustace, which lay low in the water crowded with soldiers, horses and stores. An English ship came alongside and grappled; the crew threw powdered lime into the enemy's faces and swept her decks with cross-bow bolts. She was boarded and taken after a fierce struggle. [Ref. 7: p. 64]

The description of the use of the cross-bow is noteworthy. It had been used on land since the tenth century, but when it was first applied to naval warfare is unknown. Almost certainly, the French ships had cross-bows at Dover. Perhaps the English used them to exploit their prohibition by Pope Innocent II in 1139. Described as "hateful to God and unfit for Christians", cross-bows were forbidden to be used as a means of warfare by Christians [Ref. 4: pp. 35-37]. Restrictions in their use were lifted somewhat during the Crusades permitting employment against Moslems. Sometime later they were used freely by Christians against each other.

During the twelfth and thirteenth centuries missile throwing devices were being used more widely in the Mediterranean. Mangonels and trebuchets were used to heave a variety of projectiles. Their adaptation for use on ships required that they be significantly reduced from their land warfare dimensions. They remained fairly insignificant in battle outcome however, and the longest range weapon on northern European ships of this period was the ballista, a large cross-bow. As a result of the continuous development of the cross-bow for land warfare, its use on ships was widespread. It was the primary weapon for naval actions other than ramming and boarding, until the appearance of gunpowder.

B. NAVIGATION AND DISCOVERY

The significance of the development of navigation to maritime history is underscored by the Brodies:

> Just as the opening of men's minds had to wait upon the invention and widespread use of printing, so the great developments in sea power had to wait upon the opening of oceans to navigation. [Ref. 4: p. 62]

Under Henry the Navigator, King of Portugal from 1433 to 1460, mapmaking, navigation science and ship design were advanced in a truly revolutionary way. Until his time, ocean voyages were limited mainly to the confined waters of the Mediterranean and coastal excursions along Europe. The compass had been available for about a century and the astrolabe, invented by the Greeks, for much longer. Henry took these tools and combined them with scientists, mathematicians, astronomers, chart makers and ship captains. Providing a way for inquiry , knowledge and skills to percolate together, he built an academy at which ship captains and pilots were instructed. His personal fascination with astronomy, geography and travel developed into widespread interest, voyaging exploration and discovery became a national passion. [Ref. 4: p. 62]

Portuguese caravels became the best ships afloat. Sporting three masts and several well-designed sails, the ships could beat much closer to than wind than other vessels of the day. Capitalizing on the new advances in navigation and stout, seaworthy ships the Portuguese began making extended ocean voyages. As the other European nations followed suit, the foundations of commercial power shifted decisively to Iberia, France and England. In the single century between 1425 and 1525, the maritime exploration of more than half the globe was accomplished, and included the three greatest voyages in human history, those of Vasco da Gamma, Columbus and Magellan [Ref. 4: p. 63].

Although the achievements of Henry the Navigator provided a boost of revolutionary proportions, the development of sailing ships capable of such voyaging was evolutionary. Near the end of the twelfth century the bow of European ships was strengthened and given a rounder shape, possibly influenced by merchants trying to increase cargo volume. The rudder was moved from the vessel's quarter to a centerline sternpost. Definite points in development however are made difficult to ascertain because of fragmentary evidence. What evidence is available is subject to distortion. Many of the only contemporary pictures of northern European warships of the twelfth through fourteenth centuries are representations which appear on the seals of towns and offices which dealt with maritime affairs. The confined space of the seals make the vessels appear much shorter in relation to their height than they probably were [Ref. 1: p. 23].

C. GUNPOWDER WEAPONS

Whatever its origins, the applications of gunpowder weapons to naval warfare arise from a cloudy record. The uncertainty derives partly from the variety of accounts placing the invention of gunpowder itself and partly form the plethora of changes to naval ships which occurred during the fourteenth and fifteenth centuries. Some historians consider the adoption of gunpowder weapons a slow, drawn out process. Others consider its development as curiously rapid considering the safety hazards, logistical problems, and purely cumbersome means to employ early guns of dubious effectiveness.

1. Development

Although initially used by the Chinese as an incendiary as early as 1000 A.D., gunpowder was not exploited for its propulsive power until about 1290 [Ref. 8: pp. 38-39]. The earliest drawings that clearly attest to the existence of guns date from 1326 in Europe and from 1332 in China [Ref. 8: p. 81]. By the 1350's small guns, often weighing less than forty pounds, were part of the armaments of ships. Inventories of 1410-1412 relating to the ships of Henry IV, King of England, show that the Christopher of the Tower had three iron guns and one hand gun [Ref. 1: p. 30]. Evidently all these weapons were designed with men as targets instead of ships. In the battle of LaRochelle in 1372, handguns used by both the French and Spanish played a decisive role in defeating the English adversary [Ref. 4 p. 64]. That decisive role may not have been due to the projectiles fired, however. A different account of the same battle, though not mentioning firearms, indicates that the English ships became unwieldy as the horses on board became wild and unmanageable [Ref. 7: p. 108]. The behavior of the horses may have been incited by the gunpowder weapons. McNeill writes:

> From the very beginning, the explosive suddenness with which a gun discharged somehow fascinated European rulers and artisans. The effort they put into building early guns far exceeded their effectiveness, since, for more than a century after 1326, catapults continued to surpass anything a gun could do, except when it came to making noise. [Ref. 8: p. 83]

The earliest guns were used in land warfare particularly to breech fortified walls during siege campaigns. Referred to as "bombards" these weapons were constructed by welding together numerous bars or hoops of metal to form the barrel. The materials used, usually cast brass or copper and later, wrought iron, held together weakly under the pressures of the gunpowder explosion. Loaded through the breech, the early built-up guns required great courage as well as skill. Misfires and disasters were common and put experienced gunners in a rather exclusive group. Other obstacles to the use of guns included the handling of the powder, (which often shook down to separate layers of components rendering it useless), and containing the wild recoil of the discharging weapon. Iron hoop bombards were used by the Turks in 1451 to batter down the walls of Constantinople in forty days. The same walls had withstood nearly a thousand years of siege attempts.

By the fifteenth century the bellmakers' techniques of casting had been applied to the manufacture of gun barrels in northern Europe. Over time it was found that guns cast in a single piece of bronze or brass were far more reliable than those which were built-up like the bombards. Consequently the built up method was abandoned altogether. The tendency to make new things in forms already familiar led to the first gun projectiles being arrow shaped. Substitution of spherical shot for the more slender, narrow projectile caused the gun barrel shape to change from vase-like to a tube. The tube shape permitted the expanding gases to accelerate the cannon ball through the whole length of the barrel, making possible the attainment of much higher velocities. Realization of these improvements in performance created interest in even higher velocities inducing gun makers to lengthen gun barrels to hurl heavier projectiles. Completing the circle, the use of larger projectiles required bigger charges of powder which in turn demanded stronger gun barrels. The driving impact of this series of developments on the practice of metallurgy and metalsmithing was significant.

Concurrent with changes in gun construction were developments in the operation of gunpowder weapons. Stone cannonballs were replaced with iron which made both a more effective and cheaper projectile. The much denser iron balls could only be fired from the stronger barrels of the cast guns. However, because they did not shatter on impact, the iron balls were as effective as stone ones three times larger [Ref. 8: p. 88]. Another significant technical improvement was "corned" powder. Forming the gunpowder with small grains or corns allowed more rapid, even ignition, permitting the force of the generated gases to be impulsively directed to the projectile instead of leaking around it. In combination, the cast gun, corned powder, and spherical shot reduced the cannon's size while at the same time enhancing performance. These were the changes necessary to pave the way for widespread use of gunpowder weapons on ships.

2. Early Use of Cannon on Ships

The stoutly built sailing ships of England, Spain, Holland, France, and Portugal lent themselves well to the use of guns. Since they did not depend on rowers for propulsion, deck space was available. Recoil problems, still significant were tamed by use of a carriage which rolled backwards across the deck absorbing the shock without damage to the ship. The backwards motion of the cannon also permitted access to the muzzle for reaming out residue after firing. Even with these improvements, the more powerful weapons were so heavy that they had to be placed near the waterline to maintain vessel stability. In northern Europe, such considerations led to major changes in the construction of ships. At the close of the fifteenth century, these changes were beginning to appear.

In the Mediterranean, naval warfare as it had for almost two thousand years, still centered on ramming and boarding. So the vessels of choice through the fifteenth and sixteenth centuries remained the light, fast galleys manned with large crews for rowing and hand to hand combat. Crossbows remained the long ranges weapons because the comparatively flimsy ships were nearly as liable to damage by their own gun recoil as the intended target at the end of the cannonball trajectory. The difference between the Mediterranean and Atlantic ships and their respective weaponry was substantial. By the end of the fifteenth century, the armed merchant ships of Europe had expanded their influence to the Americas and the Far East.

IV. REVOLUTIONARY DEVELOPMENTS IN THE SIXTEENTH CENTURY

A. ACCOMMODATING THE NEW WEAPONS

An important sixteenth century change was the introduction of the square transom stern to replace the rounded stern. The square flat facing made it much easier to cut gunports facing aft so that heavy stern-chase guns could be mounted. As a result of the intensifying rivalry among the European maritime powers and increasing emphasis on heavy guns, the size of warships grew tremendously. Concurrently, improvements in gun manufacture had yielded a cannon that in shape and general appearance was the smooth bore, muzzle loader of the next four centuries. The trends were typified in the English warship Great Harry. Built in 1514 the Great Harry carried 124 guns of which 43 were classified as heavy. Of the heavy guns, all but a half dozen were of a breech loading, built-up type. At 1500 tons, Great Harry was twice the size of most ships of the period and according to some, the first ship with gunports. In 1540 she was reoutfitted, and given two rows of guns per side, so that her complement of heavy guns numbered 49. About half the heavy guns were cast muzzle loaders, rather than built-up, breech loaders. The high demand for cast guns to support large continental land campaigns as well as growing navies placed great pressure on the suppliers of copper, tin, and zinc. The power of any ruler who was able to afford the high cost of the new weapons was therefore enhanced at the expense of neighbors and subjects who were unable to avail themselves of the new technology of war. [Ref. 8: p. 89]

Henry the VIII, lacking the funds to import foreign brass, brought to England a French metallurgist, Peter Baude, who succeeded in casting the first iron gun in 1543 [Ref. 4: p. 52]. Although early cast iron guns were initially inferior to brass ones, Baudes' work was significant because it shifted the center of metallurgy to England where it remained until the end of the nineteenth century. As the techniques improved, the cast iron guns, which were much cheaper, became the standard large cannon. The mid sixteenth century European warship was outfitted with one or two continuous rows of heavy guns, capable of firing a potent broadside. The possibility of severely damaging or sinking enemy vessels with this broadside called for major tactical changes. Up to this time, it had been the practice to form the fleet into a line abreast for an attack. Now it was necessary to form a column or line ahead so that, sailing parallel to the enemy, each ship could fire its broadside into the opposing vessels. In addition to the preliminary tactical maneuvers for the windward position, a position now even more important to offensive success, the ships of the fleet had to be kept in station and maneuvered as a whole during the action. Otherwise, friendly vessels fouled arcs of fire, and diminished the effect of the column's broadside. A fleet in the leeward position could break off the action and turn away more easily, and in strong winds its ships could use their lower deck guns while the windward ships, heeled over towards the enemy line, were often unable to open their partially submerged lower deck gunports.

The rapid proliferation of guns of various sizes and shape presented a major logistical problem to military commanders and rulers alike. In 1544, Emperor Charles I of Spain decreed that no more than seven types of cannon were to be used [Ref. 9: p. 128]. Henry II, King of France from 1547 to 1559 followed suit by cutting the number of calibers to six according to weight; hence the denominations 36-, 24-, 18- etc. "pounders". The English used sixteen sizes ranging from a four ton Cannon Royal, which fired a 68-74 pound shot [Ref. 1: p. 38; Ref. 4: p. 53].

The effectiveness of gunpowder weapons was taking on major tactical significance for naval warfare as they already had for siege warfare. The culverin, firing an 18-pound shot, was the long range weapon of the period. It had a "point blank" range of about 300 yards, and a random range of 2600 yards. Although the three heavier classes of cannon fired larger shot, their ranges were considerably shorter. The solid shot from larger caliber guns fired at "point blank" range could penetrate four to five feet of solid timber. Variations in shot such as chain-shot and bar-shot were used to damage masts and rigging. Scatter-shot and grape-shot were anti-personnel projectiles. Explosive shot or "bombs" were hollow cannon balls filled with gunpowder and fitted with a fuze which was lit before the shot was loaded into the gun. These frequently detonated in the cannon and the practice was discontinued except when fired from mortars [Ref. 1: p. 42]. The mortar was a very short tube, arranged at an angle so that the projectile fell nearly vertically. Initially used in the fifteenth century, mortars were generally employed in the bombardment of shore fortifications.

The changes in European ship design in the sixteenth century were embodied in the galleon. Having a much greater length in relation to beam than the earlier carracks, and a lower forecastle set back from a protruding, stem-mounted beak, the galleon became the major warship of England and Spain. The galleon had the seaworthiness to complete long ocean voyages and owing to improved sails and rigging, could "beat" against the wind. Although similar in size, the English and Spanish ships had significant differences in armaments and underwater lines, differences which affected their performance in 1588 when fleets of the two types clashed in one of the most important sea battles of history. The Spaniards built galleons in the sixteenth century as did England, but the influence of Mediterranean naval warfare had a strong hand in the shaping and outfitting of the Spanish fleet. Until 1581 when a truce between the Ottoman Empire and Spain ended more than a century of recurrent fleet actions, oar powered galleys were the mainstay of Mediterranean navies. The fact that Spain was accustomed to launching its main naval effort against the Turks inhibited the Spaniards from accepting the logic of gunned warships as whole-heartedly as did the English and Dutch [Ref 8: p. 101].

B. EARLY COMBAT EXPERIENCE

1. Lepanto

Spain's part in the victory of Lepanto in 1571 served to reinforce the anachronistic methods which subsequently doomed the Armada in 1588. Besides marking the end of significant Islamic threats against Christendom, the Battle of Lepanto was the last great naval action between fleets of oared warships. In it, a combined force from Spain, Venice, Malta, Genoa, and the Papal State defeated a similarly sized Turkish fleet.

As had been the tactic for centuries in the Mediterranean, the principal attacking movement was bow on. However, by 1571 the gun had replaced the ram as the means of inflicting damage to opposing hulls [Ref. 1: p. 35]. After initial exchanges of gunfire at long range, boarding and hand-to-hand fighting followed. The "galleass", a new type of warship which originated in Venice, was a major element of the allies' force at Lepanto. Much more heavily built than conventional galleys, and having higher sides, the galleass was an attempt to provide heavy gun broadside capability to an oared ship. But because of their great weight and heavy armament, the galleass was very slow. Indeed, so slow were they that at Lepanto, the six galleasses of the allied forces had to be towed into their positions at the van of the formation [Ref. 1: pp. 35-37].

As the opposing fleets approached each other in their line abreast formations, the heavy guns of the galleass did great damage to the Turkish fleet. Using maneuver and speed, the Turkish ships opened out to pass the galleasses and got closer to the smaller ships. Thereafter, the battle revolved around close in fighting dominated by sidearms (arquebuses), boarding tactics, and close in cannonading. Eventually, the Christians gained the upper hand, effectively ending the Moslem naval power in the Mediterranean.

2. The Armada

After Lepanto the Spanish retained many galleys in their fleet and continued their use of galleasses. Although different in appearance, the Spanish galleons retained some of the features of the oared ships. In particular they retained ramming beaks, large aftercastles with a formidable array of small, man-killing guns, and a number of heavy, but short-range ship-smashing guns. The Spaniards still considered their ships as primarily floating fortresses carrying garrisons of land soldiers for hand-to-hand combat.

It was in this way that the ships of the Armada were equipped in 1588.

The English on the other hand had recognized the tactical change imparted by an effective, (relatively) long-range broadside. Consequently, their galleons were built and armed for such combat. The English ships were built lower to the water and, because of their hull designs, were faster and more maneuverable than comparable Spanish ships. Armament of Queen Elizabeth's galleons emphasized culverins firing 18-pound shot at ranges up to one mile and demicannon, which fired a 32-pound shot effective to about 500 yards. [Ref. 4: p. 65].

Thus the principle warships of Elizabeth at the time of the Armada carried a total of 1800 heavy cannon, most of which were the longer range culverin. The Armada, consisting of 180 vessels, mounted 1100 heavy guns, only 600 of which were culverins [Ref. 10: pp. 121-122]. Another difference between the two styles of naval warfare is reflected in the manning of the two respective fleets of 1588. The English trained the individual sailor to leave his gun, scramble down the rigging, and pick up cutlass or pike for the hand to hand fighting. The Spanish considered close in combat as a primary consideration worthy of devoting the supplies and space to those most efficient at it, the soldiers. Thus, the Armada was provided with 19,000 of the land lubbers. Although some of them were part of the invasion force. [Ref. 10: p. 121]

One is certainly inclined to question the veracity of Spanish military men of the age in light of the obvious differences between the capabilities of their ships and England's. On at least three previous occasions, the advantage of gunnery over hand combat had proven itself the direction of future naval warfare. In 1509, the Portuguese achieved a decisive victory over a more numerous Moslem fleet off the port of Diu in India [Ref. 8: p. 101]. The difference was the 200 yard range of the European weapons. The Battle of Prevesa in 1538 was indecisive, but saw the Galleon of Venice--at the time said to be the most heavily armed sailing warship in the Mediterranean--repulse a series of determined attacks by Turkish galleys [Ref. 1: p. 37]. Finally, in 1587, Sir Francis Drake launched an audacious raid on the harbor of Cadiz. With four ships, Drake sank 10,000 tons of Spanish shipping, including two galleys, delaying for fifteen months the departure of the Invincible Armada [Ref. 5: p. 256]. Drakes' main weapon was the broadside of heavy guns.

Part of the problem was quixotic contempt by the Spanish for the use of cannon, which they referred to as an "ignoble arm" [Ref. 11 p. 77]. However, even those aware of the superiorities of the English ships preferred to arm themselves more with blind faith than hardware as the following passage from a Spanish observer attests:

> It is well known that we fight in God's cause. So, when we meet the English, God will surely arrange matters so that we can grapple and board them, either by sending some strange freak of weather, or, more likely, just by depriving the English of their wits. If we can come to close quarters, Spanish valors and Spanish steel - and the great mass of soldiers we shall have on board - will make our victory certain. But unless God helps us by a miracle, the English, who have faster guns and handier ships then ours, and many more long range guns, and who know their advantage just as well as we do, will never close with us at all, but stand aloof and knock us to pieces with their culverins, without our being able to do them any serious hurt. So we are sailing against England in the confident hope of a miracle. [Ref. 4: pp. 67-68]

The superior sailing qualities of the English vessels coupled with superior long range gunnery and knowledge of the local weather conditions enabled the defending fleet to conduct as series of attacks. The Armada, moving along the English Channel at the speed of the slowest ship, could make no effective response, and lost three ships and suffered damage to many others. The English galleons using their longer range but lighter guns were unable to break up the Armada's defensive formations and when the Spanish fleet anchored off Calais they were in relatively good shape, but short of ammunition [Ref. 1: p. 50]. One night while the Armada lay anchored, the British managed to send eight fireships into the harbor. The Spanish commanders, seeing the flaming ships with incendiary matter and guns exploding, panicked, cut anchor cables, and headed for the open sea. The English pursued, and in the eight-hour long fight which followed, pummeled the Spanish ships. Spanish gunnery and seamanship were helpless and only a shortage of ammunition on English ships [Ref. 4: p. 69], coupled with a sudden squall [Ref. 5: p. 258] saved two thirds of the Armada from certain capture or destruction. The subsequent homeward voyage proved much more disastrous for the Spanish, with the fierce North Atlantic gales claiming many of the ships as they sailed South along the coasts of Ireland and Scotland. More than 5000 survivors were massacred as they went ashore along Ireland. Less than half of the once proud Spanish fleet made it back to Spain.

At the time, the battle was thought to be indecisive; Queen Elizabeth like many others was disturbed that there had been no real destruction by ramming and boarding, no really close in fighting. Not a single English ship had been seriously damaged and only a score or two seamen killed [Ref. 4: p. 69]. With the exception of the fireship attack all the Armada actions had been fought by gun-fire only. Although successful in thwarting the Armada's war potential, the long range gunnery did not itself sink many ships. The Spanish galleons were sturdily built and took a great deal of punishment. In the nine-day long series of engagements during which the English had the advantage in range, only about 18 of 130 Spanish ships were sunk or captured. These results indicated that although long range gunnery was to be the focal point of future naval warfare, the guns of the day were not powerful enough to destroy heavily built galleons at the "stand-off" ranges which were being achieved. An important lesson in ammunition conservation was learned from the actions with the Armada. Early skirmishes had the English involved in useless cannonading at excessive ranges. Dozens of Spanish vessels were hit, but the damage was inflicted by only a few of the closest English ships. The others continued to fire indiscriminately and as the Armada sailed northward to escape, pursuit was halted because the English ships had run out of powder and shot.

C. RESULTS OF CANNON AND POWDER

The whole experience heavily influenced English fleet tactics for the next two hundred years. First, the tactics which best facilitated the use of long range weapons were shown to be line ahead or column formations from upwind of the target ships. Secondly, Sir Walter Raleigh forbade any gunner under his command to fire his gun at any range but point-blank [Ref 4:6 p. 69]. Thus, the method of brutal, close-in broadside engagements continued to be at the heart of England's naval warfare repertoire into the nineteenth century.

By all accounts the sixteenth century is regarded as a time of revolution in naval warfare. In summary, the combination of gunpowder, cannon, and sailing ship took naval combat from ramming, boarding and hand-to-hand action at sword's length, to pounds of cannon shot delivered at tens to hundreds of yards. That England saw the changes and adopted them, and Spain did not, altered the course of world history, and the respective roles which those nations played in it.

V. EVOLVING CAPABILITIES-CANNON AND SAILING SHIPS 1600-1815

A. LARGER SHIPS, LARGER GUNS

The main tools of naval warfare for the next two and a half centuries had already been forged. The naval cannon and stout sailing ship for all practical purposes would undergo no basic changes until the Industrial Revolution superseded them with steam, steel, and turreted naval guns. Ironically, the importance of naval power grew even though the means to enforce it did not. There were changes however, that made the execution of naval warfare more effective as a tool for both the officers and rulers who employed them.

In general, the size of guns and warships grew larger as well as did the number of guns per vessel. These trends accelerated a divergence in the design of merchant ships and warships. Up to that time merchant ships formed a significant portion of a ruler's naval power and were often built with combat as consideration. But as the specialized naval vessels grew significantly larger in the seventeenth century, the merchant ships did not, staying on the average at about 200 tons [Ref. 12: pp. 482-483]. A slimmer galleon type hull was most common with both castles gradually getting smaller.

Sail area increased with the addition of the triangular stay sails between masts, and the extensions called studding sails, to the square sails. Four masts given to some larger ships, gradually gave way to standard three mast configurations, with the sizes of each mast growing taller. Rigging arrangements were fairly standard among ships of different nations, but hull forms varied depending on such things as currents, depth of water, and weather conditions peculiar to the vessels homeport area. [Ref. 12: p. 485]

The methods of manufacturing cannon had changed little since their introduction. "Thus an account of the casting of the great cannon used against Constantinople in 1453 could easily be applied to the operations of European foundries in the seventeenth century..." [Ref. 12: p. 363]. Hollow cast iron guns introduced a century and a half before, still suffered from brittleness, and therefore had to be cast heavier to contain the force of the larger propelling charges of the day. Near mid century, the techniques changed somewhat when the Dutch devised the method of casting a solid piece and then boring it to make a cannon. The method was retained in England until 1770.

The sum total of these changes yielded no appreciable increase in weapon effectiveness. Hall writes "... the guns of Queen Victoria's wooden ships were capable of little more accurate practice than those of Drake's fleet which defeated the Armada." [Ref. 13: p. 8] With such a degree of accuracy only the close broadside tactics employed by the English and Dutch proved decisive in a sea battle. Though overall progress was not manifest in any remarkable increases in destructive power, the seeds of future evolution of naval warfare were germinating.

B. ENGLAND DEVELOPS NAVAL POWER

In England sea power was firmly established as a national priority. Shipbuilding as art, craft and science was given emphasis by the highest authorities. James I of England granted a charter to the corporation of shipwrights in 1605 in order to form a central authority for the regulation of practice and procedure in the building and repair of the royal vessels [Ref. 11: p. 15]. Another attempt to standardize the quality and construction of naval vessels was Sir Walter Raleigh's Observation on the Navy. Raleigh described six requisites for a good ship and the manner in which those qualities were to be attained. Among them: "she should be strongly built, swift, stoutsided, carry out her guns in all weathers, lie-to in a gale easily, and stay well" [Ref. 11: p. 16].

Though the well-placed attention focused on the requirements of naval vessels, the products of the shipyards of the time were not always up to expectations. Part of problem was the lack of application of scientific thought to the products of designers or the craftsmen. The same situation has been attributed to the gun manufacturing industry, and will be discussed later. Some of the specific shortcomings along these lines were that: "They (ships) were designed without knowledge of the laws governing the strength of materials, stability, and the motion of bodies through water." [Ref. 11: p. 18] With the establishment of the rival English and Dutch East India companies in 1600 and 1602 respectively, came the need for larger merchant fleets and the naval vessels to protect them. The Commission of Reform of 1618 issued a report which became the basis of the organization and standardization of the ships of the English navy. Small ships were seen as an extravagance and the Commissioners recommended that the royal navy be centered on about thirty large ships, with the merchant fleet considered as a separate service with a classification of commercial vessels based on size. [Ref. 11: p. 21]

The Commission report went too far however, and established very explicit details for the construction of naval vessels. Rigid application of the Commission specifications and firm enforcement was to contribute mightily to the thwarting of genius, experiment, and innovation in English shipyards. As a result, sophistication and quality of English warships lagged behind those of Holland and France until the nineteenth century. [Ref. 11: pp. 21-22]

The effort to develop concentrations of firepower led to the construction of triple-decked ships in England, Holland, and France. However, the principle fighting ship of most maritime nations in the seventeenth century was two-decked, carrying between 60 to 90 guns [Ref. 1: p. 53]. Other aspects of naval construction which advanced in the seventeenth century included the protection of hulls from marine pests and the modification of hull forms to the geographic conditions prevalent in the vessels' homewaters. A flatter bottom form was developed and used in Holland, Sweden and Denmark where the ships were of them employed in shallow waters. These hull types had the advantage of greater carrying capacity but could not hold to the wind as well as the deeper draft English ships. [Ref. 11: p. 27]

Main construction techniques were fairly common to European warships, with variation only in the positioning of individual parts of the hull structure [Ref. 1: p. 53]. However materials of construction did make a difference in the vessels ability to take the punishment of a thirty or forty gun broadside. In particular, English oak was unequalled by any other timber. Such was the toughness of English oak that the Dutch imported and built some of their ships of it. Not only was it strong and durable, it resisted deadly splintering, which was characteristic of the less dense wood of which many Spanish and French ships were built. This toughness lent itself well to the yardarm to yardarm slugfests which English naval tactics espoused.

During the three Anglo-Dutch Wars between 1652 and 1674, the English used the close in tactic to fullest advantage, capitalizing on both the toughness of their ships and the firepower of their cannon. Basically the method involved the directing of the cannon shot against the opposing hull, so damaging the structure and killing or wounding the crew, that the vessel ceased to be a threat. The English often sought one on one confrontations. To maneuver and control ships of a fleet in such action, the line ahead or column formation, already used in the actions against the Armada, was written in 1653 into a set of official "Fighting Instructions." These were modified in 1655 in order to establish the distance of "half a cable", i.e. 100 yards, between ships [Ref. 1: p. 54]. Both the Dutch and French used the line ahead tactics, but with more flexibility than the English. The French and other continental navies emphasized gunnery doctrine which directed fire against the masts, yards, and rigging of the adversary, using longer range guns [Ref. 1: p. 54]. Dutch variations included a "gregarious system" of mutual support of vessels by others in the force. Fireships were also stressed. [Ref. 11: p. 31]

The formalization of line ahead tactics led to the generation of orders of battle so that English ships of various rates were matched with the opposition. This prevented a smaller, less powerful ship form engaging a stronger enemy vessel in the initial engagements [Ref. 1: p. 54].

The end of the Dutch Wars 1674 brought a decline in England's navy and a rise in French naval power. Under the direction of Colbert, Minister of the Marine for Louis XIV, the French Navy and dockyards built some of the best warships of the period. In general, they were larger than English ships of the same armament. They drew less water and so their lower gunports were higher out of the water and therefore more often available for action. The French ships were also faster and more stable than those of the English. [Ref. 1: p. 53]

The superiority of the French ships was not lost to the British. In 1672, they copied the 74-gun Superbe. [Ref. 1: p. 53], and then proceeded to make nine more copies of it. [Ref. 11: p. 32] By the time the War of English Succession erupted in 1689, the English had rebuilt their fleet, along traditional lines, with shorter, larger bore guns, and narrower beamed, thicker hulled ships [Ref. 11: p. 32].

C. SEVENTEENTH CENTURY SCIENCE

The static condition of technological advance in naval weaponry during the seventeenth century was mentioned earlier. The reasons for the lack of progress are many, but in no way can it be attributed to a dearth of scientific inquiry. Kepler, Harvey, Gilbert, Bacon, Boyle, Galileo, Bernoulli, and Newton all made their most significant contributions to science during that period. Substantial improvement in the accuracy of naval gunnery had to await a correct and properly applied theory of ballistics. Niccolo Tartaglia, an Italian mathematician, published two works on ballistics in 1537 and 1546 respectively. Gunnery manuals of the seventeenth century contained many references to Tartaglia's work. Some texts included range tables and other numerical aids, but there is little evidence that they were used for anything but show. Tartaglia's renderings were mainly obscure philosophical treatises and the range table values appear to have been derived rather arbitrarily. [Ref. 14: pp. 18-19]

A correct theoretical basis for ballistics was not available until Galileo tested his mathematical derivations using contemporary artillery pieces. That too was limited because the guns were idiosyncratic and irregular in construction, powder quality varied, and windage clearances unique to the individual projectiles fired [Ref. 14 p. 19].

The real disconnect in the technical advance of armaments during the seventeenth century however, was the gap between science and imagination on one hand and engineering and manufacturing on the other [Ref. 4 p. 87]. The situation was similar to that described above concerning the application of scientific thought to naval architecture and design. Metallurgy was widely studied by scientists, physicians and alchemists. Many of the chemical writings of the day were devoted to it. Contrastingly, practical metallurgy was entirely in the realm of craft in which learning was passed down to apprentices as they developed their livelihood. [Ref. 13: p. 11]. Experimentation in manufacturing was also thwarted by the demands of nearly incessant warfare. Not only were weapons in continuous use, but the tax base for funding any development for the government had long since been decimated during some battle. When new guns were made, their cost kept quantities low and the requirements of the practicing gunner extended no further than that the replacement be as good as the old piece. Operational guns were durable enough that most could be used for dozens of years, so there was little pressure, either internal or external to produce new weapons.

As the seventeenth century wound down, the relationship among science, technology and military power began to take on meaning. It gave impetus to the growth of staffs in ministries of war and marine in Europe. By 1680, the War Ministry of France was staffed by clerks, engineers, mapmakers, soldiers and men who may have been prototypes for staff scientists. [Ref. 15: p. 41]

Under the direction of such bureaucracies came authorizations to experiment in manufacture, testing and operation of weapons. The first centers for education in artillery ballistics and naval research were also established in France under Colbert in 1679. The seventeenth century continued the germination of subtle, but important seeds of change in the technology of naval warfare. It would not be until the second half the nineteenth century that those changes sprouted and bore fruit.

D. THE GOLDEN AGE OF SAIL 1700-1815

1. Cannon and Carronade

The trends which began with the defeat of the Spanish Armada continued through the eighteenth century and roughly to the end of the Napoleonic Wars in 1815. Smoothbore muzzle loaded cannon of cast iron or bronze were the primary weapons. The 32-pounder, a six thousand pound gun of about six inch caliber, was the largest weapon on typical ships of the line. The guns were still inaccurate with an effective range of 300 yards, even though the fall of shot could easily reach over 3000 yards. Consequently, the measure of effective gunnery was high rate of fire or volume, not accuracy. [Ref. 4: p. 13]

Attempts to improve accuracy were ongoing however. British mathematician Benjamin Robins (1707-1751) put gunnery into a truly scientific domain with his work on both interior and exterior ballistics. Coupling field experimentation with theory and calculation, Robins discovered many errors in the ballistic theories of Galileo, Newton and their followers. He also helped devise means for gunners to measure projectile velocity and was the first to prove that air currents affect the flight path of a cannon ball. Robins' <u>New Principles of Gunnery</u> published in 1742 was an influential book covering scientific and engineering aspects of gunnery as well as recommending the adoption of breech-loading, rifled weapons [Ref 6: pp. 113-114]. But these developments had to wait years until metallurgical engineering could provide gun barrels strong enough to contain pressures necessary to fire heavier elongated projectiles associated with them.

Robin's work outlined in a pamphlet in 1747 was confirmed by French documents which were on board the captured man-of-war, the Mars. The manuscript contained the results and conclusions of experiments in which the French were attempting to determine the best proportions of guns and most efficient powder charges [Ref. 11: pp 121-123]. Essentially Robins stated that large shot provided greater advantage in ranging and penetration power over small shot and that in naval combat, the size of hole they make and increased penetrating power gave them a significant edge. In elaborating the details, Robins proposed increasing the caliber of smaller guns and reducing powder charges to one third the weight of the projectile in order to reduce stress to the gun barrel.

Crucial to the development of all ideas is the wherewithal, including attitudes necessary to make them reality. Such was the case with Robins, for in the British navy at the time there was enthusiasm and a search for efficiency. The proposals were well received and supported by commentaries in and out of the service. Finally under the patronage of a master-general of ordnance, experiments were conducted which confirmed Robins' results.

On a separate, but converging track, the Scottish iron founding and shipping firm, Carron Company, had constructed a very light type of gun to protect the firms merchant vessels. First introduced at a company meeting in 1778, the gun was received enthusiastically and put into immediate production and called a "carronade".

A very short barrelled, thin-walled carriage gun, the carronade had a relatively large bore. It took standard cannon shot but projected it with a smaller powder charge. The combination of small gun size and reduced charge made it ideal for space constrained merchant ships. Although the range was short the gun delivered a smashing power equivalent to much larger weapons. The effect led to some spectacular early successes as unsuspecting privateers sidled up to receive a hull pounding out of all proportion to the "victimis" size.

The reputation of the weapon spread quickly and in the atmosphere of a royal navy eager for better weapons capability, the carronade was adopted as orthodox, secondary armament on British warships. during the nest half century the carronade contributed to victory and to defeat for the navies of Britain, France, and the American colonists. The influences surrounding the use of the weapon are important, as they provide lessons which are applicable to a modern navy and deserve a closer look.

As has been mentioned, the heaviest armament of most naval vessels throughout the period was a 32-pounder of about 300 yards effective range. Standard cannon of that size and smaller had a much longer range capability, but at closer range lost their effectiveness as the vessels grew larger and thicker-hulled. The problem stemmed from the fact that weapons which had higher muzzle velocities for long range engagement, did relatively little damage at the close quarters ranges of decisive action. This was because the ball from such weapons penetrated cleanly at close range making repair efforts comparatively easy. Thus it was becoming increasingly difficult near the mid point of the eighteenth century to sink a ship by gunfire. Making the standard gun large was not the solution to the problem because manufacturing methods still could not produce a high quality bore. Fine measurements were impossible making it necessary to allow clearances called "windage" between the surface of the shot and the bore of the cannon. Additional clearance was provided to compensate the effects of wear, flaking, rust, different temperatures in locations where the gun was fired, and deposits of burnt powder. In sum, the windage was so large that up to one half of the powder used contributed nothing to the propulsive force behind the projectile. The range, aim, and general motion of shot under such conditions was incalculable. As the gun deteriorated and larger powder charges applied to make up the performance discrepancies, the cannon recoil became so violent that it was more dangerous to its crew and vessel, than it was to the enemy. Using a large cannon magnified the problem beyond the proportion of its size difference.

The invention of the carronade appeared to overcome these problems completely. The short barrel was less defective for its caliber making large windage allowances unnecessary. The tighter fitting projectile and smaller propelling charge made a very efficient combination. Recoil became much more docile permitting the mountings of the weapon on a smaller, sliding carriage. The new weapon had better ballistics, more smashing power and could be packaged into a much smaller area than the long gun.

For several years after their appearance carronades so remained in official limbo that the board of ordnance was opposed to them and the navy board gave them mild approval. In practice the ships' commanders exercised considerable discretion and authority in deciding what armament they would carry [Ref. 11: pp. 132-133]. Regardless of official sanction, through the remainder of the century the carronade played an important role in the British navy. In some actions it was the decisive weapon. The French somewhat half-heartedly adopted it, but it did not match well with their longer range tactics. The Spanish and Dutch did not carry them and some historians have speculated that certain naval battles may have turned out differently had the defeated ships been so armed. [Ref. 11 p. 135]

The origin of the carronade provides an example of how scientific efforts in conjunction with manufacturing capability yield advantages in warfare. The exploitation of that advantage by the side which correctly matches new technology with tactics, in turn yields favorable results in warfare. The end of the carronade is similarly a story in which the evolutionary process works to eliminate the disadvantages of previous weapons and without losing all the advantages.

The War of 1812 spelled the end of carronade first as a primary armament, then completely. As could have certainly been predicted, a ship armed with sufficiently accurate longer range weapons would some day hold a carronade ship at bay while reducing it to splinters. Such an incident occurred when an American frigate Essex, armed almost exclusively with carronades was defeated by the English ship, Phoebe. The former, with her maneuverability impaired by damage could not close the cannon equipped Phoebe. Essex was systematically pounded as the English captain chose a range beyond that of the American carronades. The defeat of the American ship discredited carronades as main armament. For a while afterwards they remained in limited use but were gradually eliminated as manufacturing methods began to produce lighter, more accurate cannon. [Ref. 11: pp. 138-139]

2. The Explosive Shell

Although unnoticed and hardly appreciated at the time, the vanguard of modern naval projectiles was put to use in two different places in the latter part of the eighteenth century. The first was the firing of explosive mortar shells by British 24-pounders into Spanish lines during the siege of Gibraltar 1779-1782 [Ref. 4: p. 115]. The second, in 1788, was the defeat of a Turkish squadron by a fleet of Russian long boats equipped with shell firing brass guns [Ref. 11: pp. 162-163]. In both instances the weapons were used with tremendous effect. However it would be years until the major power put the devices to extensive use. To some degree, institutionalized bias prevented more rapid development of explosive projectiles during the same period that saw solid shot diminish in effectiveness. The fear of greater destructiveness was also important, particularly with the English. What was viewed with apprehension by the British however, was sought in anticipation by the French.

Throughout the seventeenth and eighteenth centuries, the French navy had been consistently outfought by their cross-channel rivals. Towards the end of the period, the French were eagerly seeking any appreciable advantage which could turn the tide of battle at sea in their favor. It was on explosive and incendiary projectiles that they focused their attention.

Free from the more standardized and bureaucratic methods in British ordnance circles, the French continually experimented with shell firing weapons. Many found their way into use on warships, albeit in imperfect stages of development. As a result many French ships suffered fires and explosions, victimized by the weapons they had sought so fervently to provide them an edge in battle. Not until 1822 with the invention of Paxihans' shell gun would the search for a significant advantage in this area be fruitful.

The English in the meantime seemed to suppress ideas and experiments with exploding shells. An attitude developed which sought to preserve the advantages already gained and the methods by which they were achieved. Fear of the dangers of carrying combustibles on warships also dictated a direction toward conservation among the British. Finally, as there had been centuries before with the cross-bow and then the cannon, there was an element of moral revulsion against the employment of what was genuinely believed to be an agency both unfair and unchivalrous. [Ref. 11 pp. 163-164]

3. <u>Ships</u>

Naval vessels themselves grew larger up to a limit of 3000 tons, 200 feet in length and carrying over 100 guns. The majority of the warships of the period carried between 50 and 80 guns [Ref. 4: p. 113]. Continuing the patterns established in the previous century, French and Spanish naval construction was superior to the British. Generally

French ships were larger, thicker-hulled, faster, better proportioned, and better armed. Distance between gunports was larger, giving French gunners greater arcs of fire for their weapons. Following scientific research on the resistance of solid bodies to water, French naval builders worked on the development of better underwater hull forms. Their efforts paid off in the form of quicker and smoother sailing ships. [Ref. 1: pp. 61-62]

On the other hand British ships were usually seen as too small for the number of guns carried. This put them so low in the water that their lowest banks of guns often could not be used, and made them sluggish in maneuver. Shipwrights and designers were given more freedom to experiment in 1750, but during most of the century, the best English ships continued to be of copied French designs.

In 1761 the English frigate Alarm was sheathed below the waterline with sheets of copper in an attempt to protect the hull from damage by marine pests. The copper also provided less resistance to the water allowing the ship to sail slightly faster and closer to the wind. The effort was so successful that by the end of century the underwater hulls of most large warships were protected in such a manner. Another improvement in the mobility of warships was permitted of the replacement of the whip-staff tiller by the steering wheel. Although the exact date of introduction is not known, by 1710 English ships having steering wheels were in fairly common use. [Ref. 1: pp. 61-62]

Changes to the upper hull also took place during the time with gradual rounding of the bow and the building of higher bulwarks for the protection of crews. Such changes provided greater strength against the forces of both rough seas and round shot. The stern was altered first towards a circular shape, then more elliptical. The advantages afforded were greater hull strength and a much better arrangement for the direction of cannon fire from aft.

4. The Appearance of the Submarine

When David Bushnell constructed the Turtle in 1776 there had already been three recorded experiments with submersibles dating back to 1578. None of the previous attempts satisfactorily resolved the difficulty which restrained the vessels after submerging - a means of propulsion.

Powered by cranks connected to horizontal and vertical screws, Bushnell's Turtle was operated by one man. To find direction and depth the operator used a compass and a water gauge. The business end, inspired by Bushnell's desire to help his country gain independence from British rule, was a torpedo containing 150 pounds of powder. The explosive was to be attached to an enemy hull using a separate screw device. In several attempts the little submarine made it to target ships but operators could not attach the weapon because of the copper sheeting on the ship's hulls.

Robert Fulton in 1800 was the next to try submarine construction. Working in France, he attracted the interest of Napoleon with the Nautilus which he launched on the Seine. When submerged with its water ballast, the Nautilus was propelled by a hand operated, two bladed propeller. Depth and direction were controlled by horizontal and vertical rudders. Its weapon was a towed container of powder for which Fulton had devised various arming and firing mechanisms including a gunlock. [Ref. 4: p. 117]

Nautilus was very successful during several trials, and Fulton's weapons blew up several old hulks for demonstration. Fulton offered to use his invention against the British on behalf of his French hosts. Perhaps too successful, the inventor was turned down because Napoleon's Minister of Marine thought the Nautilus a barbarous invention. [Ref. 1: p. 165]

Undaunted, Fulton offered to show his invention to the British. He persuaded Prime Minister William Pitt to allow him to try his torpedoes against French ships blockading Boulogne. On the night of October 2, 1805, one of the torpedoes destroyed a pinnace and its crew of twenty-one. But the British, apparently unaware of the success, considered the experiment a failure. A few weeks later the Battle of

Trafalgar was won and British interest in the submarine evaporated completely. [Ref. 4: pp. 117-118]

As it was, the receptivity of the British to Fulton's invention came mainly from outside the service. A naval committee appointed by the prime minister to investigate Fulton's ideas was appalled by them. The First Lord of the Admiralty considered Pitt "... the greatest fool that ever existed to encourage a mode of warfare which those who commanded the seas did not want and which if successful, would deprive them of it." [Ref. 1: p. 165] Among British and French naval officers alike, the torpedo was ungallant, immoral, and in total contravention of the accepted laws of war. Once again in the evolution of warfare technology, moral repugnance provided a bulwark against change.

5. Tactics and Anglo-French Rivalry

Keeping pace with the modest developments in front line naval weapons technology in the eighteenth century, were the tactics and means to control the naval battle. The issuance of permanent "Fighting Instructions" at the end of the seventeenth century codified the line ahead as the primary British tactic. Individualism and experimentation were discouraged and courts-martial awaited anyone who broke the line in battle. As time progressed ship construction adjusted to tactical methods with thicker hulls and better sailing qualities. The lethality of cannon however, did not change for the first three quarters of the century. British

Admirals stuck to their established rules and attempted to gain the advantage of the windward position. Regardless of the degree of success of their maneuvers, many battles ended in a stalemate, as the contestants though pounded, remained afloat but incapable of decisive action.

The introduction of the carronade in 1779 marked a significant improvement in the weapons suited for the line ahead fight. But shortly thereafter, on April 2, 1782 the British won a remarkable victory at Les Saintes by departing from the line tactic and breaking through the enemy formation. The maneuver generated the sort of melee action which many British officers felt was to their advantage. Afterwards, breaking the enemy line became standard practice and was used in the majority of the six major British naval victories between 1794 and 1805. An improved flag signal code, introduced about the same time contributed significantly to the effectiveness of the new tactics. Using the flag signals, the British commander could control and issue orders right up to the moment the battle was joined.

It is fruitless to compare the eighteenth century navies of France and England only on the basis of armaments and vessels and draw any meaningful conclusions about the impact of technology on their long rivalry at sea. In the period under the consideration, 1700 to 1815, French warships were consistently better, ship for ship, than England's. This is borne out by the several instances throughout the century when French vessels were captured, copied and placed into the service of the British navy. For that matter even some Spanish ships were superior to English vessels in certain classes [Ref. 1: p. 62]. French designers and builders were freer to experiment and more circumspect in application of scientific principles to their products then their rivals. France had a larger population, more natural resources and for most of the period, overseas trade assets at least equal to that of Britain. The artillery reforms of Gribeauval marked the first significant case of command technology applied to warfare and led to changes in artillery design and practice which bordered on revolutionary in impact. Yet with all these apparently major technological influences in their favor, the French were consistently beaten at sea.

The reasons for Britains naval superiority lie in domains other than technology or for that matter innovation in general. For at least a quarter of a century from 1763 and 1789, France became the most important seat of military experimentation and technical innovation [Ref. 8: p. 161]. Such a distinction may have been indicative of deeper seated problems such as a pervasive feeling that after repeated failures anything new had to be tried in order to regain pride and military prowess. Lack of confidence led to a generally diminished naval capability for France in the first half of the eighteenth century. Seeking ways to reduce the heavy financial burden of a large navy, Louis XIV elected to turn the matter over to privateers. Without adequate protection French merchant ships were usable to ply trade routes. The result was a near strangulation of the nations commerce bringing France to the brink of financial ruin [Ref. 16: pp. 155-156]

Attempts to refloat an effective challenge to English naval supremacy produced the fine ships mentioned earlier. However, these were intermittent efforts which were opposed in the long run by Louis and Napoleon's primary focus on land warfare. Strategic schemes centered on water-borne invasion forces escorted by the navy. When these complicated plans broke down, victims of coordination requirements beyond the means available, the policy makers concluded that money spent on the navy was wasted and should be reduced [Ref. 8: p. 180]. In a vicious circle, a diminished navy failed to adequately protect commerce causing a further reduction in revenue. Without a centralized credit system such as had been established in England, local suppliers and contractors gave weak support to naval requirements and kept warships insufficiently victualed and supplied. In short, England had the means and will to build and maintain a navy which met whatever challenge was presented. As an island nation England relied on maritime power for survival. In times of crisis the taxes were raised, monies appropriated, and more ships and cannon produced. But in battle after battle the enemy's better ship's were outfought by the British with the margin of victory provided by superior seamanship, tactics, leadership, and sheer willpower.

VI. TRANSITION - THE INDUSTRIAL REVOLUTION (1815-1905)

A. EARLY CHANGES AND THEIR USE IN WARFARE

After Napoleon's defeat at Waterloo the world was ready for a lasting peace. British seapower was unchallenged. Trade between the old world and America was expanding rapidly, with the existing sailing vessels carrying on quite successfully. World powers, wary of a recurrence of the French threat and the economic consequence of large scale warfare, turned their attention to means of controlling war. Competition found its outlet in trade, with faster, larger ships and short turn around times. Shipping companies, eager to expand routes and save money, were open to fresh ideas. Military leaders, particularly those which had been victorious in the recent conflicts saw no reason to alter their ways. Success had been theirs with the means and methods in place. Why change them? The Crimean War would provide the answer to that question.

1. Steam Propulsion

Steam powered devices had been put into service to increase production and lower cost in mining and manufacturing since the earliest days of the eighteenth century. Their application to shipboard used was thwarted by their prodigious bulk, weight, and fuel consumption until the early nineteenth century. In 1801 William Symington constructed a steam engine which powered the tug-boat, Charlotte Dundas on the Forth and Clyde canal. Although successful in trials, the steamboat was not followed-up because of the fear of wave damage to the canal banks. [Ref. 17: p. 328]

American Robert Fulton, who witnessed the trials of the Charlotte Dundas, carried out more experiments on his own. He successfully concluded them in 1807 when the commercial steam vessel Clermont made the 150 mile upriver transit between New York and Albany in 32 hours. Thereafter commercial acceptance and use of steam powered vessels grew quickly. Significant naval interest in steamships was aroused more slowly. Running the gamut between suspicion and outright contempt the feelings of the British Admiralty were summed up in a statement issued in 1826:

> Their Lordships feel it their bounden duty to discourage to the utmost of their ability the employment of steam vessels, as they consider that the introduction of steam is calculated to strike a fatal blow at the naval supremacy of the Empire. [Ref. 1: pp. 75-76]

The reluctance of navies to embrace these early steam vessels is somewhat justified. Powered by large, exposed paddlewheels, they were very vulnerable to gunfire. Furthermore, the deck and hull space occupied by the paddlewheels, reduced gunnery area making the ship less potent.

Fulton built the first steam warship in 1814 with some of these shortcomings in mind. The Demologus, as it was called, was built for the United States Navy to break the

British Blockade of New York in the War of 1812. Although finished too late to see action the Demologus solved some of the problems but revealed others in the adaptation of steam power to warships. Fulton's ship was a catamaran with the engine in one hull and boiler in the other. The paddlewheel was given protection by placing it between hulls. Protection was also afforded by the five feet thick wood sheathing of the hulls. Armament consisted of thirty 32-pounder cannon and two 100-pounder submarine guns which fired underwater. Although it could travel at six knots, the Demologus' engine was above the waterline, it had a small fuel capacity, and was not intended for open seas warfare. Because of the limitations in range and the unresolved vulnerability of the steamship paddlewheel and engine, the sailing ship continued to be improved and modified as the primary vessel of war. [Ref. 18: pp. 19-20]

Following forty years of experimentation, a device which had been used for water movement since antiquity, the Archimedan screw, powered the first screw steamer, the Archimedes in 1838. The propelling screw solved two of the most serious problems facing the successful mating of steam power to warships. It obviated the vulnerable paddlewheel and permitted the prime mover to be placed below the waterline.

Swedish inventor John Ericsson had demonstrated the technical advantages of a screw propelled vessel to the

British Admiralty in 1836. In spite of his success, the Admiralty spurned Ericsson, who then took his idea to America. Working with Captain Robert F. Stockton, Ericsson designed and built the Princeton, the first screw warship. Completed in 1843, the Princeton had full broadside capability and her engine, placed below the waterline was coupled directly to the screw propeller. The year after the launching of Princeton, the iron hulled passenger liner Great Britain became the first screw propelled steamship to cross the Atlantic. France commissioned a screw warship in 1845 and Britain followed three years later with the screw frigates Dauntless and Arrogant.

The early screw propelled ships were frigate sized or less and used their steam systems as auxiliary to the masts and sails. Ships of the line were the next to receive screw propulsion, but were still viewed as sailing ships with machinery as secondary means. France, again eager to gain on their cross-channel rivals wherever they could, commissioned the 90-gun Napoleon as a screw warship in 1848. The British followed with the screw propelled capital ship, Agamemnon in 1850. By this time commercial shipping companies were investing heavily in the steamships. In the guest for expanding markets, higher profits, and prestige merchant companies backed by high stakes entrepreneurs built larger, faster, more beautiful vessels. Transatlantic steamship travel had become commonplace by mid-century. In spite of the steamships demonstrated advantages, the conservative planners of large navies remained suspicious. They were intimidated by the noise, motion, and sheer bulk of the equipment, and did not trust it. As late as 1860 the Admiralty cautioned their soldiers in official manuals:

> Engines and machinery, liable to many accidents may foil at any moment and there is no greater fallacy than to suppose that ships can be navigated on long voyage without masts and sails. [Ref. 9: p. 146]

2. Weapons Changes

Through the first half of the century the armament of capital ships of large navies was mainly the smoothbore, muzzle loaded cannon firing solid shot. The peaceful years between 1815 and 1853 offered no reasonable stimulus to change means or methods of the previous two centuries. In 1822 French General Henri J. Paxihans published a book which served notice that revolutionary change were imminent. He argued that ships protected by armor plate and carrying large caliber guns firing explosive projectiles could decimate wooden ships with complete impunity. [Ref. 8: p. 226]

The type guns to which Paxihans referred were new weapons he had just invented, called shell guns. The projectile of Paxihans' gun was like a mortar bomb, filled with gunpowder and detonated with a time fuze. Its horizontal trajectory gave the weapon greater accuracy then other cannon. Tested against old hulks in 1824, the shell gun substantiated Paxihans' forecast. The French navy adopted the shell gun in 1837, followed shortly thereafter by the British and other European navies.

In reality, the shell gun was anything but new. Sir Samuel Bentham, an English shipwright who had been hired by the Russian government, fitted out a group of vessels in 1788 with shell firing brass guns. Armed with these weapons the Russians flotilla attacked a superior Turkish squadron and annihilated it [Ref. 11: pp. 162-163]. Sixty-five years later the Russians would provide another more memorable demonstration of the shell gun's effectiveness.

While Paxihans' concepts represented more of a change to projectiles than to the cannon themselves, other, more fundamental directions were being pursued. The superior accuracy afforded by rifling had been known since the early sixteenth century. However, when rifling was done, the earliest involved straight grooves to accommodate the cleaning of the barrel and removed of residue from the previous shot. By the mid nineteenth century the serious consideration of rifling larger artillery and naval guns was frustrated by the limitations of contemporary manufacturing. The machining of gun barrels to tolerances necessary for accuracy and worthwhile ranges was not yet in reach. Another obstacle to rifling was the necessity of muzzle loading the weapons. Grooved barrels, loaded through the muzzle, proved to be so slow in rate of fire that they were a serious handicap. The obvious solution to the problem lay in the development of breechloading weapons.

Breechloading, like rifling, had been thought of long before. But as was the case in the earliest guns, imprecisely fitting parts and weak structures kept breechloading from becoming widespread for a few more years.

Recognition of the need for stronger gun barrels prompted work by Thiery, Treadwell, and Dahlgren. The former built guns in which cast iron barrels were enveloped by layers of iron cylinders, each shrunk down to the cast iron core barrel. The technique produced a strong compressive tension on the barrel, permitting larger propelling charges. Dahlgren's gun was a muzzle loaded smoothbore which was designed to place the greatest barrel thickness at the points of maximum stress. This gave the weapon its characteristic beer bottle shape. [Ref. 10: p. 184]

There were many avenues of experimentation and investigation for the developers of naval weaponry. But in the four decades of peace prior to the Crimean War, there existed a lack of urgency to bridge the gap between experimental results and weapons production. In the meantime civilian industry in Europe grew in capacity and in its ability to manufacture consumer goods. Key to remaining competitive in the growing market place, was the ability to accommodate change. The Crimean and American Civil Wars provided the stimulus to revolutionize naval warfare, civilian industry provided the means.

3. The Crimean and American Civil Wars (1853-1865)

From a political or strategic viewpoint the causes and results of the Crimean War are confusing and perhaps inconsequential. But from the aspect of the conduct of war it was of major significance. The only big naval battle was at the outset and involved a Russian and Turkish squadron at Sinope. Using shell firing, 68-pound, smoothbores, the Russian ships obliterated the wooden Turkish vessels within hours. Half of Paxihans' prediction was proven correct. The navies of the world took notice and embarked on major programs to protect ships using armor plating.

Following the destruction of the Turkish squadron, Britain and France sent forces to Crimean Peninsula. From such a distance, the allies conducted the war totally dependent on long supply lines served mainly by ships. It was in this role that steam powered vessels proved conclusively superior to sailing vessels. As the war dragged on shore bombardment became increasingly important. The French, reacting to the lessons at Sinope, constructed three floating batteries of wood and covered them with armor. These batteries were towed into action on the Black Sea by paddle-wheel steamers and on 17 October 1855, they engaged a Russian fort at Kinburn. Although the French ironclads were subjected to several hours of both solid shot and shell fire, they suffered minimally. In the meantime they forced the surrender of the fort, bearing out the other half of Paixhans' vision [Ref. 1: pp. 79-90]. It was clear even to the most conservative planners, that an effective warship must have steam power, armor protection, and some improved gunfire capability.

The Crimean War was the first conflict fought with the attendance of the electric telegraph and newspaper reporter. These two influences may have profoundly affected the means of war as they brought much closer to home the deficiencies in supply, performance, and equipment of their military. Spurred by information such as the newspaper reports from the Black Sea region, William Armstrong, an engineer in the business of hydraulic machinery, set out to improve the gun.

Coupling the science of interior ballistics to manufacturing technology, Armstrong produced a rifled, breechloading gun, which he presented for trial in 1855. Following three years of comparative testing during which it proved superior in accuracy, Armstrong's gun was adopted by Great Britain. Though the privately manufactured gun was produced in quantity, first for the Army, and then the Navy, it was only moderately successful. Critics of the Armstrong guns claimed that the breechloading mechanism was difficult to use and prone to failure. The shells which were coated with soft lead to seal in the barrel, often lost their coatings in flight, reducing accuracy. [Ref. 19: pp. 9-10]

The French complicated Great Britain's naval gunnery problems in 1859 when they launched La Gloire. At 5600 tons, the wooden hulled ship incorporated a single row of large guns, 4.7 inch thick armor platen and screw propulsion. La Gloire was impervious to any known British gun and her newer 66-pound breechloaded rifles were more than a match for the weapons of any ship afloat. [Ref. 1: p. 80]

Seizing the opportunity, Joseph Whitworth, personal rival to Armstrong, claimed to have muzzle loading rifles which were superior both in accuracy and armor penetration to Armstrong's guns. Official tests conducted in 1863-1864 proved that the breechloaders were more difficult to use and less effective against armor than the muzzleloaders. However, Whitworth's gun required a fit so close between projectile and barrel, that manufacturing methods of the day could not produce it. [Ref. 9: p. 239]

While British arms makers were demonstrating their wares to the Admiralty, shipbuilders produced an answer to La Gloire. In 1860 the Warrior was launched as the first all iron ship of the line. Warrior was nearly twice the displacement of the French ironclads, and held about one knot advantage in speed. Though the steam machinery ship was now seen as the primary means of propulsion, both the French and British initial ironclads were outfitted with full sail rigging [Ref. 1: pp. 80-83]. Warrior's armament was not significantly better than the French counterpart, but her iron hull was an indication of an underlying British strategic superiority.

As a logical consequence of the shortage of quality timber, structural limitations of wood, and tremendous increase in the size of guns and ships, iron hulls were inevitable. With numerous private yards already having experience in the construction of commercial iron steamships, British could capitalize on far greater iron producing resources and carry out large scale construction of a modern iron hulled navy.

Across the Atlantic, the American Civil War was pitting an agrarian culture against an industrialized power. The more powerful navy of the Union had established an effective blockade around Confederate ports. The Confederates following the example set by the European ironclads, built a blockade breaker on the hull of the scuttled Federal ship, Merrimac. The Confederate ironclad was armed with a combination of smoothbore and rifled shell-firing guns. What made the Merrimac unique was that it was recommissioned to operate solely on steam engines.

Likewise, the Union Monitor had no masts or sails. Propelled by a single screw, the Union ironclad was designed by John Ericsson and built completely in response to the Confederate blockade breaker. Monitor had two 11-inch

Dahlgren smoothbore guns contained in an innovative revolving turret. Covering turret and decking down to its bare one foot freeboard, was a layer of protective iron. Though capable of speeds up to five knots, the Monitor was an inshore warship like its Confederate opponent. [Ref. 1: pp. 84-85]

In the famed Battle of Hampton Roads, the two American ironclads pounded each other for four hours without inflicting serious damage. The battle ended in a tactical draw, but the Union had managed to keep its blockage intact and therefore benefitted most from the encounter. Throughout the world, navies took notice that both shot and shell were ineffective against armor. The search for improved weapons, already underway in Europe, was hastened.

Besides the first naval battle between steam propelled ironclads, the Civil War saw two other naval developments in significant use; the submarine and submarine mines. Both of these were in the service of the smaller, more innovative Confederate navy.

The H. L. Hunley was a 40-foot submarine constructed by Confederate engineers using an iron boiler. With its crew of eight working a hand-cranked propeller, The Hunley could make 2.5 knots either fully submerged or with the tops of snorkeling pipes above the surface. After two aborted outings, the second of which killed the whole crew including Hunley the designer, the Confederate submarine succeeded in its mission. Armed with a spar torpedo, the Hunley sank a Federal warship Housatonic on 17 February 1864, but was herself sunk with all hands. [Ref. 1: p. 166]

Submarine mines were used in large numbers by the Russians during the Crimean War. Both contact and electrically discharged types were planted, but were inconsequential to the war partly because of the Russians' failure to keep them within range of their coast batteries, affording the Allies the opportunity of clearing them [Ref. 18: pp. 269-270]. The Confederates however, were especially successful with mines, sinking seven monitors and armored gunboats, and eleven wooden ships, and damaging many others. Thereafter the tactical and strategic potential of mines was widely recognized. [Ref. 18: pp. 271-272]

B. THE RACE BETWEEN ARMOR AND GUNS

The ironclad experiences of the American Civil War accentuated a contest between armor and guns which began almost twenty years before the battle at Hampton Roads. Experiments by the Stevens brothers in 1843 indicated that iron plates in sufficient thickness could withstand at thirty yards, the heaviest shot in the service of the U. S. Navy. With this in mind plans were made to build a ship equipped with such armor. When John Ericsson brought his 12-inch wrought iron gun to America, it proved capable of penetrating a target as strong as the Stevens'. Thus, the designers had to alter plans to increase armor thickness and consequently the ship's size. This pattern of development, armored protection followed by the manufacture of a gun which could penetrate the armor, repeated in a rapid sequence until the end of the century. [Ref. 18: pp. 178-179]

1. Changes In Gun Construction

The progress in naval ordnance took two paths as a consequence of armor plating and iron hulls. The first and most evolutionary, was the increase in size of the weapons. For the most part these were smoothbore cast iron tubes. The use of cast iron limited the power of the gun because after a point, additional thickness yielded no increase in barrel resistance to internal pressure. The powder charge had to be small enough to be constrained by the cannon barrel. Enlargement of the bore increased the area over which the propelling force acted, but the mass of the larger round shot increased for more in proportion to the area. Other factors limiting the size of cannon were lack of homogeneity in the casting and the rapidly burning character of the gun powder. Efforts to overcome gun sizes limitations slowed with the 15-inch Rodman guns which were so effective against Confederate ironclads. By the war's end 20-inch pieces were in production. [Ref. 18: p. 185]

The large smoothbores provided good close range armor smashing capability, but new trends were dictating the advantages of long range accuracy and more rapid rates of fire. The search for these qualities lead to the developments of the Whitworth and Armstrong guns. Both types of weapons were touted as answers to the armored ship because of their rifling and use of elongated projectiles. However the use of such projectiles required a large propelling charge than for equivalently sized spherical shot. Because these Armstrong and Whitworth guns were constructed basically the same way as the large smoothbores, the rifled guns, subject to great charges, tended to burst. Furthermore, the tactics of the time called for short range engagements in order to save ammunition. With the range advantage of the rifled gun nullified by the unchanging tactics, and gunnery manufacture unable to produce a safe yet powerful enough gun, rifled ordnance was looked upon unfavorably. Opinion in the U. S. Navy was so deeply contrary that the smoothbore Dahlgren gun was the standard naval armament for twenty years after the Civil War. [Ref. 18: pp. 190-191]

The search for a stronger rifled gun lead to the second path of naval ordnance improvement, one more revolutionary in character. That path was in manufacturing of the gun itself. As early as 1847, Friedrich Krupp had manufactured guns of steel. The state of metallurgical science had not progressed to the point at which an unflawed, uniform casting could be made however, and some early failures of Krupps' guns sustained deep seated suspicions of steel. Henry Bessemer's experiments with artillery led to a new method for refining steel. The Bessemer process allowed large scale production and homogeneity of product never achieved before. The patents issued to him in 1857 ushered in a new era of metallurgical science But more time was necessary to assimilate the new steel into the manufacture of ordnance. It was during this period that Armstrong, developed the hooped, built-up gun of cast and wrought iron, which England purchased in large quantity until 1864.

2. Improvements In Protective Armor

After the contest between Monitor and Merrimac in 1862, iron armor proved far from invincible in combat. The defeat of the Confederate ironclads Atlanta and Tennessee in two separate battles focused attention solely on the superiority of ordnance over armor. The ideal of planners and designers was to achieve total invulnerability using armor. Since that level of protection was not being attained, the use of armor on warships was, by 1865, on the defensive. Questions such as how much speed had to be sacrificed to get that protection began to surface. What was becoming apparent to ship constructors and naval officers was that the speed and mobility of a warship was a lot to relinquish in vain attempts to get invulnerability.

Late in the Civil War and immediately afterwards, the controversy over armor and ordnance led to the concepts which became embodied in the battleship and cruiser. The battleship was capable, because of its heavy protection, of sustained combat. Speed and mobility limitations precluded it from being the best means of controlling sea lanes. Cruisers however, were unimpeded by heavy armor, and could be effectively used in less than outright slugfests.

As the pursuit of better protection continued, the paths of armor development followed avenues similar to that of the gun. Initially improvement was sought merely by the addition of adding more of what had already been in use: wrought iron. This avenue yielded the following sequence in the growth of iron plate armor:

1859	4 to 5 inches
1864	6 inches
1868	9 inches
1875-76	14 inches
1881	24 inches [Ref. 1: pp. 97-98]

To support the massive weight of the protective armor it was necessary to apply the thickest layers around vital areas while tapering the ends of the ship to little or no protection [Ref. 18: pp. 216-217].

The second means of gaining protection were improvements in the manufacture of the armor. Changes to weapons and protection which were associated with new materials as well as means of production were related of course. The science of metallurgy which yielded new armor is the same one which provided better guns. In the late 1870's steel was the margin of improvement.

Various combinations of steel armor were attempted beginning in 1876. Found at first to be excessively brittle, steel was later welded to wrought iron to give a superior degree of protection. The French steel producer, Schneider, who had supplied both the first iron and first steel armor, was unconvinced that homogenous steel protection was inferior and he kept up his research. Late in 1881 he produced a steel armor by a new method of oil tempering and forging. Subsequent test proved that Schneider's armor was superior to the compound armor then in favor. Thereafter homogeneous steel was improved by additions of nickel and Schneider nickel steel was the best available until the development of face-hardened steel in 1891. [Ref. 1: pp. 97-98]

The degree of protection of face-hardened, or "Harveyed" steel when compared to the old wrought iron was tremendous. Twelve to fourteen inches of the Harvey nickel-steel gave better protection than twenty-four inches of wrought iron armor [Ref. 1: p. 98]. The lightness achieved permitted its use over a larger area of the ship favoring again the armoring of smaller as well as larger ships. The trend was accelerated when just four years later Krupp's firm produced a new type armor, 20 to 30 percent more resistant than Harveyed armor [Ref. 18: p. 219]. Each succeeding improvement in armor plate allowed for the application thinner layers to yield the requisite protection. In 1898 the British *Formidable* class ships had only nine inches of Krupp armor.

3. Converging Weapons Improvements

Concurrent with armor developments were changes to guns, projectiles and powder, making the period from 1875 to 1900 one of most revolutionary in the history of naval warfare. Recalling the muzzleloader versus breechloader controversy surrounding the Whitworth and Armstrong guns, an accident on HMS *Thunderer* in 1879 led to the decision in favor of breechloading weapons. Following a misfire, one of *Thunderer's* muzzle loaded guns was mistakenly reloaded with a second charge and second shell. When fired again the weapon exploded killing eleven and injuring thirty-five. It was determined that such an accident would have been impossible with a breech loading weapon. [Ref. 1: p. 112]

Although precipitated by the accident aboard *Thunderer*, the adoption of steel, breech loading guns was made possible by improvements to steel and to the manufacture and assembly of breech mechanisms. A converging development was the improvement in gun powder which permitted the lengthening of gun barrels to achieve higher muzzle velocities. The slower burning, smokeless chemical propellants made longer barrels an advantage by providing a propelling force over a longer period of time. The lengthened barrel however, could not be loaded efficiently through the muzzle. When confidence in steel guns and breech mechanisms was finally gained, all the advantages of the disparate improvements were packaged into the large naval gun in use today.

Mounting the large guns was a significant problem of the late nineteenth century. Where the weapons were placed on the ship, affected their degree of usefulness. Hydraulic systems which could move the huge pieces became necessary and, when put together in an armored enclosure mounted on the centerline of the ship, the large turreted gun became the standard arrangement for the major caliber weapons. This provided the degree of protection, range of motion, and stability necessary to support the big guns in a tactically useful condition.

Projectiles fired by the rapidly improving gun were themselves being transformed. With attention initially given purely to armor penetration, projectiles underwent a series of changes between 1878 and 1896. Hardness, construction and types of caps were varied to achieve the penetrating power necessary to puncture the hardened steel armors. In 1895 a "semi-armor piercing" shell was developed which carried a five percent capacity bursting charge that exploded part of the way through the armored plate. This line of development carried on through the turn of the century.

A final development in naval gunnery during the last quarter of the century was the quick-firing gun. Stimulated to some extent by the tactical handicap of the slow rate of the breechloader, a gun which fired at the rate of twelve aimed shots per minute was produced in 1881. At the time, the breechloaders larger than 12-inch caliber were firing at the rate of one every two minutes [Ref. 1 p. 112]. By placing the projectile and propellant in one cartridge, using a rapid working breech lock and a quick-return recoil device, high rates of fire were achieved in weapons up to 6-inch caliber. These smaller guns had the addition advantage of requiring a much smaller gun crew. [Ref. 18: p. 225]

The major importance of the smaller, faster firing gun was magnified by increasing ship speeds, the ponderously slow fire of the larger guns, reduction in number of weapons each ship carried, and the lack of proper aiming and sighting devices which could capitalize in the ranges at which the guns were effective.

The Battle of the Yalu River in 1894, between a Japanese and a Chinese fleet served to highlight the advantages of the quick-firing gun. The ten ships of the Chinese fleet centered on two heavily armored German-built battleships. Then opposition was a relatively weaker force which contained several of the newer, faster protected cruisers sporting many of the 6-inch and 4.7-inch fast firing guns. The fire of the Japanese ships annihilated the Chinese cruisers, but failed to inflict any vital damage on the two armored battleships. The Japanese flagship suffered three hits and was put out of action, but damage to the others was minimal [Ref. 1: p. 123]. After losing five of his ship the

Chinese admiral was forced to withdraw in defeat [Ref. 7: pp. 188-189].

Critics of lightly armored ships argued that the Chinese crews were imcompetent and their ammunition defective (one of the three shells which hit the Japanese flagship was a shell filled with cement instead of explosive). Supporters of faster, multi-gun ships claimed that the Yalu battle confirmed their opinion [Ref. 1: p. 123]. When the American and Spanish navies fought at Manila and Santiago during the Spanish American War, the technologically inferior Spanish ships were literally shot to pieces. The large 12-inch and 13-inch guns on the American ships were thus touted as examples of the importance of large guns. The results, when viewed more critically revealed deplorable weakness in the ability to use the available firepower. In the flat calm of the Manila Bay action the U. S. ships hit their stationary targets only 2.5 percent of the time even at 2000 yards. At Santiago under similar weather conditions, not a single 13-inch round found its target, while the 12-inch guns had only 2 strikes. Only 3 percent of all guns, firing 8000 rounds, found their marks. [Ref. 20: pp. 45-46]

Whatever the actual results were, the direction of naval capital ship construction following the Sino-Japanese and the Spanish-American Wars took two separate paths. The "predrednaughts", mounting four or more 12-inch guns with 6- or 8-inch secondary armament, protected by 9- to 12-inch nickel or chrome steel armor was the battleship. The second, smaller ship was the armored or "protected" cruiser mounting a large number of 8-inch and 6-inch, quick-firing guns.

The capital ship of the end of the nineteenth century had a top speed of almost 20 knots, independent of wind. Displacing between 6,000 and 15,000 tons, the steel armored behemoths provided stable platforms for huge guns which could launch one ton projectiles a distance of ten miles. In each of these qualities the capital warship of 1900 exceeded the wooden hulled ship of the line of 1850 by several orders of magnitude.

In spite of the marked increase in warship capabilities, particulary in ordnance, the ranges at which the ships drilled and fought was only slightly greater in comparison to the previous era. The British fleet carried out target practice at ranges of couple thousand yards even though gun maximum ranges were nearly ten times that distance [Ref. 1: p. 125]. During the battle of Manila Bay in the Spanish American War, the U. S. ships opened fire at 5,000 yards but had to close to 2,000 yards in order effectively hit the stationary Spanish fleet. At Santiago, in the same war, the ranges were between 1650 and 3500 yards [Ref 3: p.97]. Considering the appallingly low percentage of shots which were on target, the conclusion might be drawn that nineteenth century technology had not advanced naval warfare very much at all.

C. OTHER DEVELOPMENTS IN NAVAL WARFARE TECHNOLOGY

Displaced somewhat from the main avenue of naval warfare were developments which lead to the creation of a new type of vessel, major changes to the capital ship, and the waging of naval warfare in a second dimension. Introduced prior to the twentieth century, the locomotive torpedo the reaction turbine engine and the submarine would affect naval warfare in revolutionary fashion during the next major war.

The first locomotive torpedo, created in 1867, was driven by a compressed air engine. Named after its Scottish inventor, the Whitehead torpedo carried an 18 pound warhead at six knots for a few hundred yards. In a few years it became part of the regular armament of major warships. Continually improved, the end of the century torpedo weighed 1200 pounds and travelled 800 yards at 30 knots. By virtue of its gyroscopically controlled steering device, it was much more accurate than its predecessors. The success of the early Whitehead torpedo coupled with the apparent effectiveness of small, maneuverable craft in the American Civil War led to an interest in small torpedo boats. Among the lesser maritime powers, as well as those seeking a fiscally austere means of naval capability, the prospect of attaining a large fleet of torpedo boats instead of only two or three cruisers had definite appeal. By the last decade of the nineteenth century, the torpedo boat had become so numerous and effective that it had to be countered in some way. That counter was the torpedo boat destroyer, later called simply, a "destroyer."

Destroyers were essentially larger torpedo boats mounting a battery of quick-firing guns and a set of torpedo tubes. The extra size permitted larger engine spaces giving the destroyers a necessary speed advantage. The quest for higher speeds produced the destroyer H.M.S. Viper, the first warship propelled by a reaction turbine engine [Ref. 1: pp. 158-159]. Vipers turbine engine was epochal in modern warship propulsion systems. Although it was uneconomical at low or moderate speeds, the turbine engine provided unmatched power and reliability in a structure which was only a fraction of the size of the multiple expansion, reciprocating engines it replaced. Matching these smaller, more powerful engines with larger, more heavily armored destroyers resulted in ocean-going ships which became an essential feature of all navies by 1900.

The development of a submarine warship had stalled because it lacked an effective propulsion system and an effective weapon. The Whitehead torpedo solved the weapon problem by 1885. Independent attempts to use coal-fired steam power in submarines led nowhere. In 1888 a submarine designed by Spaniard Isaac Peral was launched which incorporated two 30-horsepower electric propulsion motors and a piloting tower. Peral's boat was unstable when submerged however, and not very successful. In the same month, the French launched the *Gymnote*, a cigar shaped submarine, possibly inspired by Whitehead's torpedo. The little French submarine was powered by electric motors and solved the previous nagging problem of submerged stability by incorporating hydroplanes. The *Gymnote*, though experimental, was a great success and marked the beginning of a series of French advances in submarine design and construction. [Ref. 1: pp. 167-169]

Characteristically leading the way in innovation, the French launched the first truly sea-going, submersible war vessel in 1899. Designed by naval constructor Maxine Laubeuf, *Narval* was a double hulled vessel which had torpedo boat qualities when surfaced. Its oil-fired boiler and triple expansion engine gave *Narval* a 500 mile range at six and a half knots or a ten knot maximum speed. Electric motors propelled it over six knots when submerged, and by virtue of its periscope *Narval* could be navigated while underwater, making effective use of its four torpedoes. [Ref. 1: p. 169]

Meanwhile, the United States was the only other power to set about the systematic development of a submarine force. The *Holland*, named after its builder, was the first modern submarine completed for the U. S. Finished in 1900 *Holland* was smaller than the French boats, but superior in performance. Using an internal combustion, gasoline engine she could cruise 1500 miles on the surface at seven knots. Battery powered electric motors gave Holland a 50 mile range at almost seven knots. Her armament consisted of three tubes, two for firing dynamite shells when on the surface, and one for a Whitehead torpedo. Holland was accepted by the Navy and formally commissioned in October 1900. Six more submarines of the same type, but armed only with a torpedo, were delivered to the U. S. Navy in the next few years [Ref. 20: pp. 289-290].

By the end of the nineteenth century, naval forces had available all but one of the modern weapons delivery platforms. Surface ship capabilities covered the spectrum from battleships to torpedo boats. Although not yet proven in combat, submarine delivered torpedoes were at least conceived as having important warfighting potential. Advances in technology had produced powerful units of naval warfare. Ancillary developments in communications, optics and electronics would provide the means to form the units into cohesive fighting fleets during the next two decades.

1. Planning for And Using Change

The Spanish American War had established the United States as a primary naval power. New weapons and machinery played an important role at Manila and Santiago, but it was obvious that the full potential of the new means of warfare had not been truly exploited. Technological change was occurring rapidly and displacing much of the traditional knowledge and methods of naval warfare. The establishment of the Naval War College in 1884 was an effort to provide the new knowledge and intellectual framework into which the new devices of sea power could be exercised. Alfred T. Mahan, the second president of the Naval War College published ten books elaborating the concepts of seapower as a basis for national policy. Mahan's works, appearing between 1890 and 1900, further whetted the appetites of these who favored naval expansion, and in doing so he emphasized the importance of an offensive navy built around large ships.

Between 1890 and 1900, the Naval War College became heavily involved with war planning. Participating in games which were developed around real political and military situations, the games players drew up various plans and exercises which could be applied to actual forces. In essence the Naval War College had become a naval general staff. This type of activity was a logical consequence of having no equivalent body of officers to do such planning. Recognition of the lack of a central coordinating body for naval planning caused the establishment of the General Board of the Navy in 1900. The General Board was commissioned to advise the Secretary of the Navy on war plans, basis and general policy. Thus the Naval War College and the General Board were primarily concerned with devising ways to use the technological marvels at their disposal.

As the General Board matured the need for technical considerations in planning became apparent. In 1909 Admiral Dewey pointed out to the Secretary of the Navy that no official process insured that proper military features were designed into ships. Concerned particularly with ordnance, armor, torpedo installations, and a host of other things, Dewey recommended that planning for such things be made part of the routine process of naval ship design in the U. S. [Ref. 21: p. 123]

Similar changes were underway in Britain where private arms manufacturers had wielded enormous influence over the shape of the navy. The willingness of the public to finance the private industry of warship construction had fanned the flames of technological innovation. As each naval building program unveiled new changes, they opened avenues of future innovation. This required even larger naval appropriations for the next round of construction. With the Admiralty providing the financial assurance necessary to complete work to specifications, inventions became deliberate. When the process was finally matched with the intellectual foundations of Corbet and Mahan, strategy and tactics began to shape the warships within limits set by technical considerations. [Ref. 8: pp. 278-280]

This overall scheme of government requirements stimulating technological advance has become known as "command technology." Spurred by the intensifying rivalries such as between Germany and England, ambitions focused government and public resources on capital ships. In Germany's case, Admiral Tirpitz persuaded the Reichstag to pass the second of two German Navy Laws in 1900 calling for a fleet of 38 battleships, 20 armored cruisers, and 38 light cruisers [Ref. 22: p. 4]. Tirpitz was inspired in large part by the writings of A. T. Mahan [Ref. 2: p. 284]. On ground fertilized by the intellectual, political, and technological fervor of the day, scientific discovery continued to blossom. Advances in electricity were hastened by commercial markets for Edison's light bulb and the electric generator. James Maxwell's work in the theoretical realm of electromagnetism, along with that of von Hemholz and Hertz gave Marconi the background for the wireless telegraph. In 1902 and 1903 Nobel prizes were awarded to Wilhelm Roentgen and Pierre and Marie Curie for the discovery X-rays and isolation of radium respectively.

There were many other discoveries and inventions at the beginning of the twentieth century, but their telling is beyond the scope of this paper. What is important is that the climate for research led to discovery, and political and military ambitions motivated efforts to apply the discoveries in new ways toward the means of warfare. But improvements were not always nor often the quick, isolated adaptation of a new gadget or device. The time between the manufacture of an advanced piece of hardware and its successful integration into the growing fleet, was measured in years. Delays were forced by lack of opportunity to adequately test innovation, lack of sufficient motivation to change, bureaucratic mazes through which ideas had to be guided, and the hallmark of peacetime Western military institutions--cultural resistance to change.

One of the most significant improvements to U. S. naval warfare effectiveness was achieved in spite of the obstacles mentioned above, and did not involve any new inventions or machines. It was the continuous-aim gunfire system devised by Sir Percy Scott of the British Navy and brought to the United States and perfected by William S. Sims.

Disturbed by the poor marksmanship of the Navy in the recent war with Spain, Sims intensified a search for better gunnery skills which he began years earlier. While serving in the Far East, he had observed the aiming methods used by Scott making the HMS Terrible the crack gunnery ship of the Royal Navy. Scott perfected a way to allow his gunners to keep their sights fixed on target despite the rolling of the ship. A training aid known as a "dotter" was also devised and used on the British cruiser, and enabled the gun crews to practice their continuous aim firing without expending any ammunition [Ref. 23: p. 244]. Finally, Scott used telescopes which he had modified for the gun pointers' benefit, having cross-hairs in the lenses instead of the notched sights common to other guns.

As late as 1898, prior to Scott's changes, typical Royal Navy gunnery practice was held at 1,600 yards, the effective range for weapons which could fire a projectile out to 20,000 yards. Within six years the effective range of the Royal Navy's ships had increased by a factor of ten. Recognizing the importance of such relatively simple methods for improvement, Sims sent reports of his findings, endorsed by the commander in chief of the Asiatic Fleet, to the secretary of the Navy. Following unfavorable review by the chief of the Bureau of Ordnance, Sims' report was stalled.

Firmly convinced of his ideas and undeterred by lack of official blessings, Sims wrote directly to President Roosevelt. As a former assistant secretary of the Navy, the President was fully aware of the implications of Sims' report. Handling the situation delicately but firmly, Roosevelt had the young navy lieutenant installed as inspector of target practice. From such a position, Sims was able to make the necessary changes to fleet gunnery methods. Within 18 months American gunnery standards exceeded those of the Royal Navy, not only in accuracy, but in rate of fire. [Ref. 23: p. 244]

The ability to deposit energy on target accurately at far greater distances than previously achieved was only one aspect of change inspired by Sims. He also agitated for changes in design and construction of the U. S. battleships. Pointing out the defects of the ships of the Great White fleet, Sims criticized the low freeboards, the openness of the ammunition hoisting system which could allow flaming debris from the gun breeches to pass into powder rooms, and gunports so large that turrets offered little protection to guns and crews [Ref. 23: p. 244]. Such shortcomings directly affected battle efficiency in rate of safe gun firing and ability to withstand damage.

Sims carried his criticism to the number and type of weapons the ships were given, questioning the logic of such practices as mounting 12-inch, 8-inch, 7-inch, and 3-inch guns all on one ship. He advocated as early as 1901 the construction of ships with just two calibers of guns: the largest, for battle against capital ships, and small rapid-firing guns for protection against torpedo-boat attack. Sims and a classmate, Homer Poundstone, drew up plans for such a ship which they called the Skeered o' Nothin, but these were pigeonholed in the Bureau of Construction and Repair for years, with no action taken on them. [Ref. 24: p. 405]

On December 12, 1901 Guglielmo Marconi sat in a little room in Newfoundland and listened to three short sounds in a device with which he had been experimenting since 1894. The sound originated from electric signals sent by his assistant in England. Wireless had crossed the Atlantic [Ref. 25: p. 117]. The development of a means of communication other than signal flags and searchlights had great implications for naval strategy and tactics. It provided the afloat commander with a longer range, all-weather means of directing his fleet and it gave naval shore headquarters the means to inform and direct the actions of the distant fleet commander. So obviously important was this capability that unlike most innovations, the development and fleet adaptation of wireless (radio) communications was universally accepted without opposition [Ref. 10: p. 208]. Part of radio's widespread welcome may have been its rather benign origin. As early as 1900 The British government had equipped one of its lightships with the new wireless for experimental purposes. Only a few weeks after it was installed the lightship was rammed and its crew saved because help had been summoned from shore by wireless [Ref. 25 p. 118].

D. PUTTING TECHNOLOGY INTO ACTION: THE RUSSO-JAPANESE WAR

The Russo-Japanese War of 1904-1905 was the backdrop of the first great fleet actions of the twentieth century. It pitted large gun, pre-dreadnaught capital ships against one another as well as against mines and torpedoes. It also underscored the importance of wireless communications and accurate intelligence information.

In the first battle, at Chemulpo, Korea on 9 February 1904, Japanese Commander Togo sent his torpedo boats into action against seven Russian battleships and six cruisers, all at anchor. The torpedo attacks caused some damage but new torpedo nets which had been deployed around the anchored ships prevented the sinking of any of the Russian vessels [Ref. 5: p. 672]. At Port Arthur, both sides laid minefields attempting to bottle each other up in port. On 13 April, the Russian flagship Petropavlosk struck an electromechanical mine which detonated the ship's magazines, sending her 600 crewmen and the fleet commander to the bottom [Ref. 5: pp. 672-673; Ref. 20: p. 52]. The Japanese lost two of its largest and newest battleships, also to mines, a month later.

The battle of the Yellow Sea, 10 August 1904, was the first naval action of the war which involved extensive gunfire. Up to that time the most effective weapons had been torpedoes and mines. The Russian fleet attempted to break out of Port Arthur and steam to Vladivostock. News of their departure was radioed to Togo by naval wireless operators who were manning fishing boats in the area. The Japanese commander, acting on the intelligence, used his superior speed to intercept the Russians. A long series of gunfire exchanges out to ranges of three miles ensued. [Ref. 5 p. 674]

The accuracy of the gunfire on each side was not much improved from that of the Spanish-American battles. Sanderson indicates that after the range decreased, the Japanese flagship Mikasa "was repeatedly hit" [Ref. 7: pp. 192-193]. Macksey's account is a little more specific:

On this occasion the issue was settled during a long engagement by a mere four shots out of the thousands of all calibers fired and dozens of hits scored. Just two 12-inch hits on the Japanese flagship Mikasa seriously impaired the fleet's communication and gunnery, while two 12-inchers landed on the Russian flagship Czarevich killed the admiral, produced disorder and led to a precipitate Russian retreat....[Ref. 22: p. 52]

Accuracy was not the only problem. The Japanese armor piercing shells were apparently less effective than expected [Ref. 5: p. 674]. Direct hits were essential and near misses counted for nothing. The Japanese victory owed more to the simple ability to engage, by virtue of radio intelligence and superior speed, than to their better weapons.

In the months between the battle of the Yellow Sea and May 1905, Admiral Togo repaired his ships and practiced gunnery. He was getting ready for what became the culminating battle of the war. The forces on each side were impressive with the edge in weapons apparently favoring the Russians. Their seven battleships carried 41 10-inch or 12-inch guns against a total of 16 12-inch guns on the four Japanese battleships [Ref. 20: p. 54]. As in the Yellow Sea action, however, Togo's ships were faster, his crews more proficient and he had advance radio information on the location and movements of the Russian fleet.

Cued by a wireless message from one of his scouts, Togo put his ship into action at sixteen knots compared to ten knots for the two Russian columns [Ref. 5: p. 679]. The Japanese ships maneuvered quickly and smartly to cross the enemy "T" and achieve superior firing position. Togo's ships opened fire with accurate, rapid broadsides quickly damaging several enemy ships. The Russian fleet was thrown into wild confusion as the well-ordered Japanese fleet closed to their ideal range of 5000 to 5500 yards and delivered their punishment methodically [Ref. 20: p. 54]. At dusk, Togo's heavy ships withdrew having sunk three battleships. With the advantage of nightfall, and the Russian fleet in utter disarray, Togo sent his destroyers and torpedo boats into action. Throughout the night about 100 torpedoes were launched, with only seven hitting their targets. Those which did strike home were devastating, sinking two battleships and two cruisers. The next day, surviving Russian ships were hunted down and sunk. [Ref. 20: p. 54]

Of 38 Russian warships which started the battle, 29 were sunk, captured or destroyed. The Japanese lost 117 men killed, the Russians, 4830 [Ref. 7: p. 185]. The victors emerged from the war as a formidable military and naval power. They had seen that accurate fire by a few large guns could be decisive at sea, and that radio communications allowed control and coordination of attacks with unprecedented effectiveness.

E. THE DREADNAUGHT

The results of naval engagements of the Russo-Japanese war were studied intently. Tactical lessons were drawn out, argued, and analyzed. The technical details of the ship's involved were also studied, comparing weapons, propulsion, protection, and fire control. Speed was seen as a common denominator of superiority and the ineffectiveness of smaller caliber weapons against armor was underscored. This latter point had been made by Sims, leading to his still dormant plans for an all big gun battleship. Italian Vittorio Cuniberti had also campaigned in favor of the all big gun Ship. While these issues were discussed around the world, the British under the influence of Admiral Fisher, began to build the Dreadnaught in 1905.

The British Dreadnaught was extraordinarily innovative compared to contemporary capital ships. Powered by 23000 horsepower Parsons Steam turbines driving four screw propellers, the 18,000 ton warship could make 21 knots with reliability that was unmatched. After a month's steaming in the West Indies, she travelled 7000 miles at 17.5 knots without a single defect [Ref. 1: p. 132]. No reciprocating steam engine could ever achieve such sustained performance. Furthermore, the ship was equipped to burn fuel oil instead of coal, giving it one third greater range than contemporary battleships [Ref. 8: p. 281].

On the business end, Dreadnaught mounted a main armament of ten 12-inch guns in five twin turrets, an anti-torpedo boat battery of 27 3-inch quick firers, and five 18-inch torpedo tubes which were fired below the waterline [Ref. 1:

p. 129]. Connecting the main armament like the nerves of a powerful muscle, was the innovative central fire control system. Inspired by the work of Captain Sir Percy Scott and American Captain W. S. Sims, the fire control system combined range finding devices, plotting machines, precise gun calibration, and electric communications [Ref. 20: p. 56]. The observation crews were trained to spot the fall of shot and pass corrections to the gun operators. Facilitated by having guns of the same caliber the fall of a salvo could be adjusted in successive firings. Done rapidly enough and coordinated between alternating turrets, the target would have moved very little between firings. The result of this technique gave the Dreadnaught unexcelled accuracy at ranges up to 20,000 yards, over twice that of any hits scored during the Russo-Japanese War [Ref. 16: pp. 234-235]. Whether or not the concepts built into the Dreadnaught made all other battleships of the time obsolescent as most historians have claimed, it is true that her merits were incorporated into most large warships built after 1906. The basic technologies of that epochal ship remained stable for the next thirty years. A turbine powered, multiple screw armored ship, mounting a main battery of large guns housed in centerline, trainable turrets is an appropriate description of all later battleships.

Evolutionary changes consisted of increases in gun sizes, armor thickness and propulsion power with an overall effect of greater ship size. Germany emphasized more armor, wider ships, and an innovative protective measure known as "elastic bulkheads." This latter feature was designed to absorb the shock of torpedo explosions and proved to be remarkably effective in World War I [Ref. 1: pp. 132-136]. That the German navy built such features into their ships several years prior to 1914 indicates the degree to which they realized the potential of undersea warfare, something which became their hallmark and forte in both world wars.

Great Britain and the United States concentrated on firepower improvements. Gun sizes went from 12 to 13.5 inches on the British ships and up to 14 inches on U. S. battleships. Turrets were placed one over the other (called superfiring), providing much increased arcs of fire of up to 160 degrees per turret. This arrangement also facilitated the consolidation of machinery, magazines, and handling rooms to enable better compartmentation. Fire control systems were improved to the point that consistent accuracy out to ten miles was achieved. As all of these features were improved and added, the size of the battleships grew. By 1917, several countries had commissioned ships of up to 32,000 tons, capable of speeds up to 23.5 knots. [Ref. 1: pp. 132-136]

Admiral Fisher's emphasis on speed led to the application of Dreadnaught ideas to cruisers. He scorned the armored cruisers of the day claiming that they could neither fight nor run. The compromise took shape in the battle cruiser. Mounting weapons like a battleship, but sacrificing armor for speed, the battle cruiser had an approximately two and a half knot advantage over the battleships. The idea was that the superior speed of the cruiser could allow it to stay just out of harm's way, while being able to deliver punishing gunfire of its own. The concept would have been viable had gunfire control systems been better.

Such a system may have been made available in 1913. It was devised by a private citizen who claimed to have solved the mathematical and mechanical problems of placing accurate gunfire at long range from a moving, tossing platform. Constrained by financial difficulties and possibly blinded by institutional bias, the Admiralty selected an inferior system, designed by its own experts. Equipped with such systems the thinly armored battle cruisers could not exploit their long range weapons. Recipe for disaster in these ships was essentially completed by keeping in force target practice regulations which limited firing ranges to 9000 yards. The decisions which were made to keep costs down would be very expensive at Jutland. [Ref. 8: pp. 294-298]

VII. THE GREAT WAR

A. SUBMARINES AND TORPEDOES

After the U. S. Navy commissioned its Holland design submarines, several countries, including Great Britain built boats with the same or similar plans. Russia, Sweden, Italy, Germany, Japan and France all experimented with various other designs as well. The internal combustion engine alleviated some of the surface propulsion obstacles by eliminating unbearable heating of the inside of the hull by boilers. Initially the engines were gasoline powered, but the highly flammable fuel and explosive vapors created unacceptable hazards. Germany began to experiment with the diesel compression ignition engine in 1905, finally building a satisfactory diesel powered boat in 1913. [Ref. 6: p. 181]

As the propulsion system developed, the most advanced combination of diesel engines powered the boat on the surface at about 15 knots. While running, the diesel charged large sets of batteries which provided the electricity to run the electric motors. The motors which were used during submerged operation providing short bursts of speed up to 11 knots in the most modern boats of 1914.

Besides the propulsion systems, the submarine was given added buoyancy through a system of ballast tanks which were set between an inner pressure hull and outer hull. Such a design, along with diesel propulsion, was incorporated in the

D-class of British submarines introduced in 1911. These were Britain's first truly ocean going submarines. [Ref. 1: pp. 173-174]

The submarine was almost universally regarded as a defensive weapon prior to July 1914. The German Navy saw them in this role until after the war broke out. Senior officers of Britain's navy were mostly hostile toward the adoption of submarines in the service. In words applied to several other weapons innovations during history, Admiral of the Fleet, Sir Arthur Wilson judged the submarine as "Under-hand, unfair and damned un-English" [Ref. 30: p. 29]. The two men responsible for the early development of Britain's submarines were First Lord of the Admiralty, Sir Winston Churchill, and Admiral John Fisher, the mind behind the Dreadnaught. Working largely against the tide of an opposition majority, Churchill and Fisher supported the submarine branch and the construction of more submarines and better, longer range torpedoes.

Continued efforts to improve the Whitehead torpedo resulted in major increases in range. In 1905, the guaranteed range was 2190 yards. In 1906, it was 6560 yards and by 1913, the torpedo could travel over 18000 yards, nearly the range of effective gunnery [Ref. 8 p. 284]. With such a long range weapon guided by a gyroscope which could direct a turn of up to 90 degrees after launching, the submarine had a truly offensive capability. When the new torpedoe was coupled with a platform such as the British E-class boat, having a cruising radius of 4000 miles and surface and submerged speeds of 15 knots and ten knots respectively, the submarine's war fighting potential could no longer be ignored. [Ref. 22: p.29]

Meanwhile, Germany was building and improving their submarines at a rapid pace. Gyroscopic compasses were perfected and installed on all German U-boats after 1908. Sizes increased from 238 tons to 465 tons within four years, while surface speeds increased from eight to fourteen knots over the same period. When the U-19 was commissioned in 1913, its new diesel propulsion system gave it a combat radius of 5000 nautical miles. The British estimated its range at less than 1500 miles and thought their own E-class boats were far superior. [Ref. 18: pp. 297-298]

Regardless of the capabilities endowed by technology, tactical and strategic employment of the submarine was largely an unknown, untried entity at the start of World War I. Germany tended to confine its use to reconnaissance when it opened the submarine war on 6 August 1914. Though unsuccessful, the first military mission included in the first attack against an enemy by a submarine employing a self-propelled torpedo. In that same set of initial operations, two of ten pre-diesel boats were sunk, one by ramming, the other possibly by a mine. [Ref. 18 p. 300].

Lack of success by the Germans was no comfort to the British naval authorities as they increased security of the Grand Fleets' anchorage at Scapa Flow. Following a number of successful operations against military targets, a German U-boat scuttled a small commercial steamer in 20 October 1914. Shortly afterwards, the German High Command realized that it was more efficient to sink smaller vessels with gunfire than using expensive, bulky torpedoes, of which the small boats could carry only a few. They then secretly fitted out their larger submarines with guns [Ref. 6: p. 182]. The official authorization to sink commercial as well as naval shipping was issued 18 February 1915 and the U-boat took a more destructive turn.

In the course of the next few months, the U-boats inevitably came across neutral shipping, some of it American. Incidental contact led to sinkings and loss of U. S. goods and lives. Vehement protests by Washington led to incredible restraint and concessions by Germany even though the U-boats were enormously successful. German naval officers thought the U. S. demands for a cessation of the commerce raiding as intolerable. Political considerations prevailed for approximately a year as the German government curtailed their submarine attacks on commerce.

At the time Germany had a small number of submarines available but Britain was unprepared to deal with even those. Lacking sufficient numbers of destroyers and torpedo boats, an unabated war on commerce would most probably had brought Britain to her knees. As it was, the year long respite provided the breathing room necessary to develop antisubmarine warfare capability to at least marginal effectiveness, and saved thousands of tons of shipping that would otherwise have been sent to the bottom. [Ref. 18: pp. 306-307]

The Kaiser authorized resumption of unrestricted U-boat operations beginning 1 August 1916, as larger, faster boats were delivered to the German fleet [Ref. 4: pp 182-183]. The ill-prepared British defenses began to take shape in convoys and government husbanding of science and technology. Through the first four months of 1917, Allied shipping losses mounted, but the technology applied to the defense against the submarines was beginning to be felt.

Two devices which resulted from war inspired, command directed technology were the hydrophone and the depth bomb. The former was used successfully in April 1916 to locate a submarine which was caught in a mine net. Once found, the boat was quickly destroyed [Ref. 4: p. 184]. Three months later the motorboat Salmon located a submarine mine-layer by using its hydrophones. The surface vessel then dropped one of the new charges causing detonation of the sub's mines [Ref. 4: p. 184]. Other, more expedient means included the use of decoy vessels called Q-ships which were armed, but disguised as innocent merchantmen. Against such a threat, the U-boat commanders had to abandon surface engagements completely. While causing the faster exhaustion of torpedo resources, this forced the more sinister prospect of being attacked by an unseen unenemy without prior warning.

The development of the Mark H antisubmarine mine early in 1917 was an important contribution by British scientists. Once the manufacturing assets were placed in high gear in the U. S. and Great Britain, sufficient Mark H mines were produced to effectively blockade Germany and cause significant attrition of her submarines.

The airplane was an important detection platform against submarines. In shallow water the boat's shadow could be discerned by airborne observers who then radioed contact position information to destroyers. A special type of aerial bomb was also developed by the British for exclusive use against submarines. Thus the airplane too, became a deadly force against the undersea boats.

Although new devices were sought and used in the campaign against the submarine, it was a combination of new and old which provided the Allies the margin of victory. Convoys were very effective, but involved no new technology other than radio communications. Mines destroyed many subs and did make use of some technological advances, but their overall effectiveness cannot be measured simply by how many boats were sunk. Fear of mines was based in historical use and caused submarine commanders to take more circuitous routes, reducing their effectiveness and increasing their exposure to detection. Overall, however, the greatest offensive threat to the U-boat came from increasing numbers of destroyers and small craft armed with depth charges. [Ref. 4: p. 185]

B. THE AIRPLANE

1. Early Development

Early experience with aviation in war centered on reconnaissance. Lighter-than-air craft were used by land armies of France, during the French revolutionary wars, the U. S. army during the Civil and Spanish-American Wars, and by the British in the Boer War. Some efforts had been made to drop bombs from these balloons, and above several thousand feet they were invulnerable to small arms fire. However, their mobility depended entirely on wind; offering the operators little control over altitude, speed or direction of travel. Seeking to eliminate these undesirable vagaries, many inventors tried to apply aerodynamic theory to machines and structures during the first decade of the century.

As early as 1898 the military applications of an engine powered flying machine were given serious consideration in the United States. Assistant Secretary of the Navy Theodore Roosevelt, impressed by Professor Langley's "aerodrome", commissioned an investigative board composed of Army and Navy Officers and a Naval Academy mathematics professor. The board interviewed various civilian authorities, reviewed all available records and reports of experiments, and studied

Langley's device thoroughly. They summed up the potential use of aeroplanes in three roles:

1. as a means of reconnaissance or scouting with the capacity to carry an observer.

2. as a means of communications between station isolated by water or land.

3. as an offensive device, able to drop explosions from great height into enemy fortifications and camps.

The board concluded with recommendations that Professor Langley continue his experiments and implied that Navy funds should be expended for such purposes. [Ref. 26: pp. 1-2]

The report endorsed by Secretary of Navy Long was sent to the Board of Construction. The Board's verdict was that, as described in the report, the aeroplane was applicable to the Army and not the Navy. Furthermore, the Board felt that although it could not adequately consider the subject, the Navy Department should not continue experiments or furnish money for the purpose. Based on these findings, the Navy declined to match Army funds for the Langley experiments. [Ref. 26: pp. 1-3]

The U.S. Navy's high-level reluctance to indulge in flying machines continued for the next several years. In the meantime the Wright brothers conducted the first successful machine powered flight and Bleriot crossed the English channel in an airplane. Put to the challenge by a New York newspaper, Glenn Curtiss in 1910 dropped makeshift bombs onto a simulated battleship. Scoring hits from an average height of 300 feet, the military possibilities for aircraft were demonstrated. Commenting on the tests he observed, Rear Admiral Kimball still saw only the limitations of the craft. He cited the lack of ability to operate in average weather at sea, the noise of motor and propeller to alert targets, difficulty in estimating range, and problems with operating high enough to give the airplane a chance and still be effective. [Ref 26: p. 6]

Late in 1910 a commercial steamship company planned to conduct a flight from one of its ships to a shore landing spot. The experiment was postponed due to bad weather. Hearing of the idea, Captain Washington Irving Chambers then assigned to the Navy Department to coordinate aircraft developments, obtained permission to use the cruiser Birmingham to do the same thing. The steamship and Navy groups worked feverishly to be the first to accomplish the feat. On November 12, the commercially sponsored attempt had an accident during final preparations. With the added time, Chambers' organization got Birmingham ready and on 14 November, Eugene Ely flew his machine from the temporary flight deck to a safe landing on shore. [Ref. 26: pp. 10-12]

The success of Ely's flight widened Navy interest and led to similar experiments including the first landing aboard a ship in 1911. Resistance to the machines was firmly entrenched however, and those opposed used every opportunity to kill the idea. Such attitudes were on Chambers' mind when he chose not to conduct an experimental bombing of an old battleship. Though offered the chance to use real explosives in the test, Chambers knew that aircraft were not yet powerful enough to carry sufficient weapons to damage the ship without getting too close to its guns. His dilemma was that a failed test would serve to undermine his program, but to refuse the test would be an admission of the airplane's weaknesses. He decided on the later course. It was another ten years before bombing from planes was tried again. [Ref. 26: p. 20]

The situation in Europe was significantly different. The hard prejudice which accompanied the development of submarines did not burden naval aviation. In Britain the apostles of innovation for aircraft happened to be the same ones who espoused the Dreadnaught, the battle cruiser, and submarines- Churchill and Fisher. The service tended to view the airplane as an aid to improve battleship firepower, but Churchill and his deputy were determined to bring aircraft into the contemporary naval scene as a weapons platform. [Ref. 22: p. 31]

British aviation experimented with machine guns, torpedo attacks, radio communications and aerial combat since 1911. Submarine detection was tried in 1912, a role which would prove fruitful during the World War. Like their American counterparts, however, the British concentrated on the seaplane rather than wheeled airplanes operating from the decks of ship. Framed in this way, the utility of airplanes in an ocean environment was severely limited.

In the First World War therefore the airplane could not become as decisive a factor at sea that it did on land. The great capital ships which formed the core of fleets were immune to the small payloads of the still fragile airplanes. Speeds of 70 miles per hour with operating ceilings of 13000 feet were usual, and provided ranges of about 250 miles without bombs. Airships had more lifting power and range, but were much slower. The hydrogen which filled the great lifting bags was explosive, further reducing their desirability to the British. Germany however placed great emphasis on their huge Zeppelins.

2. Airplane Employment in the War

Limitations notwithstanding, England and Germany each employed the airplane in a number of naval warfare missions. Torpedoes and bombs were dropped on merchant ships by both sides, with varying degrees of success. Airplanes of the Royal Navy shot down Zeppelins, escorted convoys, hunted for submarines, spotted for gunfire, and bombed U-boat bases.

In the antisubmarine warfare role, planes played their greatest part. Operating in conjunction with destroyers, they informed the ships of sighted U-boats and directed them to the scene to attack. When sightings were made of surfaced boats, seaplanes could themselves attack. The impact of airplanes was not only in boats sunk, but in keeping the U-boats submerged and incapable of offensive actions. [Ref. 18: p. 395]

The effectiveness of aircraft led to more extensive attempts to defend against them. One of the best methods, the use of other aircraft, depended on accurate machine gun fire. The invention of the mechanical interrupter gear permitted the firing of the gun, directly ahead of the pilot and through the whirring propeller. Accuracy of fire improved phenomenally, ushering in the development of the fighter planes. [Ref. 20: p. 74]

Emphasis on seaplanes as the expedient means of employing aviation at sea, thwarted effective mating of ship to airplane before the end of the War. A number of commercial steamers were converted to carry several seaplanes each, but their role was simply to transport the aircraft to a position and place them on the water by crane so the plane could take off. One of these ships, the Engadine, provided the only plane in the air during the Battle of Jutland.

Not until September 1918 was the first clean-deck carrier placed in service. Converted from an Italian liner, The Argus' flight deck was uninterrupted by stacks, superstructure or guns and she proved capable of landing wheeled aircraft of the day safely. The Argus design was followed in the Royal Navy for the next ten years. [Ref. 1: p. 206]

Though America's slow approach to the matter would continue for some time, some important studies were made before and during the War. Successful catapults devices were developed by December 1912 and in 1913 the Massachusetts Institute of Technology established a course in aerodynamics and asked the Navy Department to furnish an officer qualified to prepare and conduct it. Aerial photography, radio, gyroscopic stabilizers, bombing and aerial combat had all been investigated by the time the General Board issued its 1916 report the possible naval uses of aircraft. Continuing to view it as a scout, spotter or patrol asset, the Board held that aircraft would remain in a subordinate fleet role. The board recommended that limited aspects of naval aviation should still be pursued, but the narrowness of their view virtually guaranteed a secondary status for aircraft [Ref. 26: pp. 62-63]

C. CAMPAIGNS AND ACTIONS

The new technology which equipped the opposing navies of World War I had for the most part been untested in battle. Early actions at Coronel and the Falklands in 1914 demonstrated that the predreadnaught era, embodied in the defeated armored cruisers had given way to the dreadnaught type battle cruiser. The fast super-dreadnaughts with their thick protective armor and massive guns were the most apparent manifestations of modern naval warfare. Capable of speeds up to 26 knots, the largest ships could hit target 20,000 yards away with projectiles weighing more than one ton.

Changes of the previous decade had multiplied more than simple firepower, however. The entire fabric of warfare at sea had grown in complexity and rearranged the order of importance of many factors. An example was the time between sighting the enemy and engaging him. At Trafalgar, five hours elapsed between the time Nelson sighted his opponent and the time he opened fire. After four and half hours of cannon fire, at ranges as little as ten yards, not a single ship had been sunk. The first exchange at Jutland in 1916, occurred just eighteen minutes after the opposing forces sighted each other. Within an hour, two of Beatty's battle cruisers had blown up and two others severely damaged. Hits had been made at ranges of over 15000 yards. [Ref. 22 pp. 267-268]

The big guns which carried out the destructive power at Jutland were the main instrument of naval combat to most authorities at the time, but fear of torpedoes and mines dominated the tactics issued in the British Grand Fleet Battle Orders [Ref. 22: p. 268]. Even though the largest guns of the battle cruisers and battleships easily out distanced the torpedo threat, and German U-boats could scarcely make ten knots submerged, they entailed such risk to the British commander that avoidance of them led to indecisive action and lost opportunity for overwhelming victory. Contributing to Jellicoe's misplaced fears were conflicting false reports of enemy submarines and general paucity of any other sighting reports from subordinate ships. [Ref. 22: p. 280]

The rigid, centralized control of the British fleet depended on adequate communications. Radios, by that time installed on all the ships larger than destroyers, were supposed to play a key part in the flow of information to the flagship. The performance of these new marvels in combat conditions was not foreseen. Antennas were carried away, transmitter sets damaged by shock or shellfire, transmissions were jammed by the Germans, and when they were available, the systems were not efficiently used by subordinate commanders [Ref. 22: p. 280]. The irony in this case as with the weapons was that technology provided capability which was not used in a way which significantly aided the victors.

The use of aircraft by the British was similarly non-contributory to the outcome of the battle, and similarly, the potential was much greater. Owing to early problems the seaplane carrier Campania which had been operating with the Grand Fleet for more than a year, sailed two hours late when the fleet departed for the Jutland action. Campania's ten airplanes could take off rapidly from her recently lengthened flight deck, and with their four hour endurance, the little planes most certainly would have been able to provide Admiral Jellicoe more information than he was receiving from elsewhere. However, lacking confidence in her usefulness and fearful of U-boats attacking the unescorted carrier, the commander of the Grand Fleet sent Campania back home. [Ref. 22: pp. 283-284]

Vice-Admiral Beatty, Jellicoe's subordinate and in command of a squadron of battle cruisers ahead of the main body, had in his group the Engadine a small seaplane carrier. Beatty sent up one of Engadine's three planes, which within twenty minutes sent back a report detailing composition, heading and relative position of a group of eight enemy ships. The pilot followed up his initial report with amplifying information including a course change by the German ships. After the little plane returned to the Engadine in what was the first ever aircraft reconnaissance flight against an enemy fleet in action, no more flights were authorized. [Ref. 22: p. 284]

The aftermath of the Battle of Jutland was that although the Germans experienced fewer ships sunk and less than half of the personnel casualties, its surviving units were so battered that they were not effectively used as naval force for the remainder of the war. The British ships were on the whole faster and more heavily gunned, a trend which had been established centuries earlier. Once their 15-inch guns entered the action, the newest British battleships could stand off and shoot thousands of yards beyond the range of the largest (12 inch) German weapons. At that phase of the battle, the Germans fleet had no recourse but to evade using darkness while the supposed U-boat threat to kept Jellicoe at bay.

In contrast to the furious, often spectacular actions between the high-profile capital ships, the U-boat war and naval blockade of Germany were conducted with comparative gruelling regularity. In these aspects of naval warfare, technology played roles as important as in the battleship or battle cruiser engagements. Advances in propulsion and control systems gave submarines maneuverability, speed, and range necessary for ocean combat activity. Torpedo developments had generated a weapon with speeds of up to 44 knots for 3750 yards or 28 knots for 10,000 yards [Ref. 1: p. 249]. To defeat the U-boats armed with such deadly weapons, the Allies relied on simple, low technology concepts combined with new weapons. Convoys and large numbers of escorts were somewhat the embodiments of the concentration of force idea applied to naval warfare. Aided by new technologies of airplanes, depth bombs, hydrophones, and in some case radio direction finders, the campaign against the German submarine force was through slow attrition.

The blockade of Germany was partly intended to lure the High Seas Fleet out to destruction by the Royal Navy, and partly to keep its own maritime interests secure by keeping U-boats in port [Ref. 27: p. 127]. Although it succeeded mildly in these respects, the great effect of the blockade was the slow strangulation of the German economy and means to wage the war. The increasingly deprived population was driven to insurrection, apathy and demoralization [Ref. 31: p. 321]. In this effort too, basic naval warfare concepts were the foundation for actions implemented with the tools of new technology. On the German side, radio was valuable in saving many of her merchant ships from destruction early in the war. Given advance information, the ships put into neutral harbors to avoid British warships [Ref. 25: pp. 122-123]

By mid war however, the only vessels which safely entered or departed Germany, were her submarines. The Allies tightened the blockade by more effectively using many separate assets as one force. Technology provided this capability by improving coordination in the form of radio communications, and increasing the surveillance area covered in a given time. The latter, a product of aerial reconnaissance served by balloons, dirigibles, and especially airplanes.

Thus, the Great War had two distinct types of naval campaigns. The more spectacular and arousing engagements between men-of-war was the type which was initially thought to be the decisive one. Here, the principals used technology incompletely, inappropriately and ultimately, indecisively. In the second type of campaign, the use of new technology was more effective when correctly used, and less catastrophic when incorrectly used. This was perhaps due to more deliberate nature of those activities. It was also due to the rate at which change can be absorbed. Over the long haul of the war, the opportunities for using new equipment (and new methods) were more gradually and effectively assimilated because of exposure to situations which were not a threat to the whole fleet. In other words, individual ship sightings, actions by destroyers against single U-boats, and the relatively benign operations of scouting and patrol allowed room for error and experimentation. A final factor in the successful use of innovation was the level of the experimenter. The main battle fleets, as showpieces of their respective navies were closely controlled by traditionally conservative, more prominent officers. The destroyers, patrol boats, airplanes and submarines were more commonly under the authority of "young turks" who were less averse to risk and more likely to embrace change.

VIII. THE MODERN ERA

A. INTERWAR YEARS

Arms control and disarmament treaties of the interwar years probably did as much to stimulate advances in warfare as any other factor. Innovation however, was applied to technique rather than new equipment. Both the Armistice and the Treaty of Versailles gave the majority of the world a false sense of security by fostering impressions of Germany as disarmed, weak, and financially broken. Playing in these perceptions, German's leaders had managed to reduce the bill for war reparations by more than 40 percent and by organizing international sympathy, secured hundreds of millions of dollars in credit and loans. Pacifists in the U. S. and Britain chose to see the money as rebuilding Germany's economy and public works when in fact it subsidized major rearmament. [Ref. 5: pp. 757-761]

The Washington Naval Treaty of 1922 was an effort to curb the growing race in battleship construction between Japan and the U.S. One escape clause permitted conversion of capital ships to aircraft carriers, thus greatly accelerating construction of the latter. Attempts to work around the treaty limitations on displacement led to new fabrication techniques and use of new materials. Electric welding and aluminum alloys were both introduced to save weight [Ref. 1: pp. 190-191]. Further weight savings were achieved by improvements in boilers and use of large diesel engines. More efficient, smaller propulsion systems gave the capital ships top speeds of over 30 knots and at the same time increased operating ranges.

With the increased size of the aircraft carrier spawned by the terms of the Washington Treaty, airplane development was given a boost. Public interest in the daring deeds of post war stunt pilots kept an even pressure on the quest for more speed, higher altitudes, and more nimble airplanes. The world speed record of 1922 was 200 miles per hour. By 1928 it was 318 miles per hour [Ref. 20: p. 104]. As operating altitudes went up the performance of engines changed, leading to the development of superchargers and variable pitched propellers. New materials gave added strength to structural members while simultaneously reducing weight. Because political desires were still expressed in disarmament and reduction of military expenditures, the aviation sections of the U.S. Army and Navy had to keep abreast of airplane developments by participating in civilian sponsored races and contests.

Meanwhile, Japan was busy developing her military aircraft industries. With experience gained in Manchuria, aviation engineers designed superior fighters and torpedo planes. Research in air delivered weapons yielded torpedoes which could be dropped from a height of 300 feet at 250 knots. By combining improved torpedo tactics with dive bombing from high altitude, the Japanese developed a powerful naval offensive capability. When protected by fighter planes the strike aircraft and their potent weapons made the aircraft carrier the deadly force Japanese naval planners had anticipated. Subsequent action in China in 1937 served as the proving ground for the Japanese carrier force. But not until the attack in Pearl Harbor would the remainder of the world be as convinced of the aircraft carrier's war potential.

The aircraft carrier was essentially a product of World War I for which the sagacious Japanese were the first to develop effective strategy and tactics. Many technical improvements in submarines, ships, weaponry, and fire control and direction systems were also made in the interwar years, building on the experience and lessons of the previous war. Most notable of these were the British Asdic (after Anti-Submarine Defense Investigation Committee), the magnetic influence mine, and radio.

One of the most important inventions of modern warfare was the radar. Although the British, Germans, and Americans had for several years experimented with radio transmission and echo phenomena, it was the British who in 1935 first set up a satisfactory system to detect airplanes in all types of weather. The system could determine range and direction from which the target airplane came and provided information necessary to compute its course and speed. From late August, 1937, radar stations around Britain were built and manned, figuring prominently in the defense of the island nation during the Battle of Britain. In 1939 the U.S. Naval Research Laboratory installed a radar set on the USS New York and earlier, the U.S. Army tested radar equipment in controlling antiaircraft guns. By 1940 the British had turned their radar research over to the Americans where a rapidly developing electronics industry put its resources to work manufacturing radar equipment to support the British war effort.

B. WORLD WAR II

By the time the U.S. Navy had been brought into the age of the aircraft carrier in December, 1941, all the naval weapons of World War II were in production or on the drawing board. During the next four years, the capital ship of the fleet became the aircraft carrier with the battleship, though still powerful, taking a secondary role. Airplanes gave fleet commanders the ability to engage targets hundreds of miles distant, and as the Japanese had demonstrated, the targets did not have to be at sea or even naval assets.

The Battle of the Coral Sea, 6-8 May 1942, can be viewed as the first of "modern" fleet versus fleet engagements. Although the opposing fleets were made up of cruisers, destroyers and aircraft carriers, the combat actions were carried out entirely by airplanes. Ships of both forces were damaged and sunk, without either ever coming into visual contact with the other.

Radar and airplanes permitted the fleet to control a much vaster area than ever before. Without proper logistical support, the influence was evanescent at best, especially if significant combat was experienced. The development of logistics support ships and the means to deliver their cargos to the hungry battle fleets while at sea, thus extended the duration and hence the range over which the fleet exercised control.

During the first year of the War the only defense which surface ships had against airplanes were other airplanes or massive amounts of small and medium caliber gunfire. Two devices developed during the war greatly enhanced the surface ships defenses against the air threat. These were the proximity (or VT) fuze and the computer. The VT fuze was a by-product of radar. When built into an explosive shell, a small radar set activated the detonator when it detected the target at proper distance. This obviated the requirement to compute the correct time of flight and setting of the fuze prior to firing the gun. Use of the VT fuze alone improved antiaircraft gun effectiveness by a factor of five. [Ref. 4: pp. 213-214]

Computer aided fire control was the second major improvement in shipboard antiaircraft systems. Charles S. Draper's invention of the Mark 14 sight, a gyroscopic lead computing device used with a 20-mm. machine gun was one of the earliest. Although the Mark 14 was very effective, the electronic M-9 was a superior director. When synchronized electrically to move with the director, the guns could be accurately and quickly brought to bear on the target by the director officer. The computer kept track of roll, pitch, and the parallax between guns and director. [Ref. 4: pp. 215-216] The computer directed fire control system was eventually coupled with radar, and faster firing guns. Perhaps the apex of this branch of weapons development is the U.S. Navy's Close In Weapons System (CIWS) using the Vulcan Phalanx 20-mm Gatling gun. Using a radar system which tracks the target and the outgoing projectiles, the CIWS corrects the error angles between the two by moving the gun until both target and projectiles are coincident on each other.

Technological developments during World War II solved dozens of separate combat problems or provided the innovators with some advantage. Yielding faster, longer range airplanes capable of carrying larger bombs, giving torpedoes acoustic homing devices, improvements in the sensitivity of sonar systems, all of these advances were discrete elements of a war which was eventually won by destroying the enemies' ability or will to continue waging it. In simplest terms, the Allies destroyed the Axis powers' means of waging war faster than it could be rebuilt. Viewed from the opposite perspective, the Allies were capable of manufacture and production in a capacity beyond which Germany and Japan could destroy it. Unlike wars in the eighteenth and nineteenth centuries, World War II involved large elements of the civilian population of most of the belligerents. However, like wars of the past few centuries, it produced weapons which had capability far beyond what contemporary strategy, tactics or doctrine could handle. In the case of World War II these were the V-2 rocket and the nuclear weapon.

C. POST WORLD WAR II

Nuclear energy, both as a means of destruction and as a means of power generation, establishes a sort of boundary for modern naval warfare. Within that boundary the technology of today's naval forces and the concepts of their use are extensions of centuries of development. Frames of reference for the sake of understanding potential non-nuclear conflict could be reasonably deduced based on past actions. In contrast, the relevant technologies and concepts of naval warfare involving nuclear weapons, dates only back to August, 1949, when the Soviet Union became the second nation to detonate a nuclear device. From that date nuclear war at sea became possible, but its characteristics and features can only be imagined.

1. Conventional

The evolutionary trends which have yielded the means of conventional naval warfare of today include the following:

- longer range weapons
- greater speed, range, payloads in aircraft
- more complex, less manpower intensive systems
- greater surveillance and detection ranges
- longer endurance of platforms

Using only the organic assets of a modern aircraft carrier battle group the radius within which surveillance, defense and strike capability can be sustained is conservatively placed at 375 miles on the surface, 75,000 feet up, and over 1000 feet below the surface.

These are considerable capabilities indeed until one assesses the potential threats to such a battle group. One of the unique characteristics of modern weapons technology is that it makes powerful, effective weapons available to a large number of organizations. This is due to the transnational qualities of late twentieth century technology and to the proliferation of armaments through commercial firms. In the sphere of naval warfare the most common types of these high technology weapons are antiship and surface to air missiles. Qualitatively, the differences between these and similar weapons used by the superpower navies are slim. The consequences in what has been popularly called "low-intensity conflict", are that multi million dollar naval assets are placed at risk by small, "smart" weapons valued at thousands of dollars, operated by Third World countries or terrorist organizations.

The political implications of super power patronage of the Third World country using such weaponry are significant. Militarily it has the potential to create much more serious, possibly nuclear, conflict. The situation has somewhat of a historical analogy in the strategy of a "fleet-in-being" used by France in the eighteenth century and by Germany in World Wars I and II. Essentially the fleet-in-being was a fleet technically and/or numerically inferior to the adversary (England, in the three cases mentioned), but which had as its purpose useful degree of command of the sea without having to force the issue through decisive battle. Such a strategy may employ harassment or evasion, thereby denying a stronger enemy the capacity to use his superiority [Ref. 32: p. 111]. Carried to the extreme, the rocket firing Iranian Revolutionary Guards, in their Evinrude powered Zodiac boats are an audacious example.

2. Electronics

One of the most subtle, but important trends of naval warfare since World War II is the trend toward information dependency. The flow of information between the fleet and its headquarters, as well as the flow between the fleet units and the flagship has become much more critical to the successful execution of naval missions. Aside from the bureaucratic requirements of peacetime navies, the importance of information to the combat missions are due to:

- the increased speed of platforms, with concommittant decrease in reaction time

- range over which the fleet operates

- scope of the naval warfare missions (i.e. subsurface, surface, air, land)

- greater sensitivity to political concerns

The quantity of information has increased with the greater sensor ranges of the fleet and with the more prominent role of outside intelligence services. As the operating units of a force have become more widely dispersed, to cover a greater surveillance area, the need to process more information has dictated greater dependency upon computers.

A second information trend is related to the development of more autonomous weapons systems. Active radar seekers, infrared detectors, semi active homers, and acoustic homing torpedoes are examples of systems which process significant amounts of information on board while enroute to the target. The sensors on board such weapons are vulnerable to defeat by deception in the form of chaff or flares to provide false targets, or sensory overload by jamming with an active radiation source. Radio communications are subject to similar actions. These electronic countermeasures are in todays' naval warfare environment what smokescreens were to the navies of World Wars I and II.

The integration of devices such as guided missiles, computers, jet engines, and sonar to naval forces met with relatively little resistance from within the U.S. Navy. In each case, they were improvements or adjuncts to the primary platforms already in existence as the contemporary fleet unit. In the author's opinion, this made them less of a threat to established institutions, traditions, and methods. Revolutionary change however, as with steam engines, airplanes, and submarines were forcefully resisted because they entailed unacceptable risk to current systems.

3. <u>Nuclear Weapons Related Technology</u>

The first use of nuclear weapons in 1945 provided a clear indication that in sheer destructive power, they were revolutionary. For a short time afterwards, there were many in power who believed that strategic bombing would be the single decisive means of future warfare and that only small contingents of ground and naval forces would be necessary. The three years of conventional warfare in Korea from 1950 to 1953 proved otherwise. It also underscored a need to add flexibility to the early nuclear arsenal.

The revolutionary impact of nuclear weapons is that their potential destructiveness is so great that their use poses the threat of annihilation of all of civilization. Beyond this feature the considerations and patterns of development for successful integration into naval forces has many of the same general earmarks as the adoption of gunpowder weapons.

The first atomic bombs weighing approximately five tons each, were so large that only the most powerful aircraft could deliver them. The bombs themselves required very unique logistic support in manpower, equipment, and method of handling. Their use in warfare was obviously not applicable in all situations because of the special support required, the nonspecific destruction caused by their relatively untamed energy, their scarcity, and their high cost. The early delivery systems, modified B-29 bombers, were also few in number and limited in range, payload, and speed. All of these limitations could be used to describe the early cannon of the fourteenth and fifteenth centuries.

Attempts to adapt the fission weapons to naval warfare led to cumbersome arrangements involving the Navy's long range patrol plane, the P2V Neptune. As the only Navy aircraft capable of carrying the bombs, they were the unanimous choice. At dockside, one or two Neptunes would be hoisted aboard one of the three largest carriers then in commission (Midway class). The carrier would steam out of harbor, and launch the Neptunes. In wartime, the planes were supposed to fly their nuclear attack mission and then return to land base or ditch at sea in a prearranged rendezvous with a waiting U.S. submarine. Tests in 1948 and 1949 proved the concept, but deployment based on the idea did not occur until 1951, after the Korean War began. By that time AJ-1 Savage, a carrier based plane, was in use and it augmented the Neptune arrangement. [Ref. 28: pp. 17-19]

The means of assimilation of the early atomic weapons continued along the same track with the addition of jet propelled A3D Sky warriors as a delivery means. Likewise, the *Essex* class carriers were modified to handle nuclear weapons increasing the number of platforms from which nuclear attack missions could be flown.

The explosions of the first fusion, or thermonuclear device in November 1952, was a culmination of work motivated by the desire to stay ahead of the Soviets. However the technology which produced the fusion bomb and continued vigorously thereafter, led to more efficient and smaller, as well as more powerful weapons. These developments permitted the flexibility and operational compatibility necessary to fully assimilate nuclear weapons into naval warfare.

In 1956 the U.S. Navy first deployed substantial numbers of nuclear capable jet aircraft. During the next three years the naval nuclear arsenal expanded in more than simple numbers. Nuclear warheads were deployed as torpedoes, surface to air missiles, and depth bombs in 1958, 1960, and 1961 respectively [Ref. 29: p. 43]. This expansion of nuclear weapons indicated that submarines and aircraft were potential nuclear targets along with ships, cities, and land forces concentrations.

The integration of the new weapons deliverable by manned aircraft, ships, and submarine torpedoes represented traditional methods of employing a revolutionary technology. This tie to the past, coupled with an institutional desire within the Navy to remain a viable force in the nuclear age reduced the perceived risk of adapting the new technologies associated with nuclear fission and fusion. The blossoming of nuclear technology stimulated more revolutionary developments however, both directly and indirectly.

As a direct application of the power of the atom, the nuclear reactor propulsion system was developed. Under the farsighted, contentious genius of Hyman G. Rickover, the U.S. Navy built the first nuclear powered warship, the submarine _Nautilus_. Able to travel thousands of miles submerged, without refuelling or having to snorkel, the _Nautilus_ was the first true submarine vessel. The complete independence of her propulsion machinery from logistic support made the _Nautilus_ a revolutionary influence on naval warfare. The manner in which Rickover brought nuclear propulsion to the fleet was largely responsible for its impact. While it is quite likely that nuclear power would have been adapted for naval propulsion plants without his influence, the political, industrial, and bureaucratic coalitions set up by Rickover allowed him to accelerate the process by several years. Edward Beach has compared Rickover and his high level political patron, Henry Jackson with the Sims-Roosevelt connection of the turn of the century [Ref. 24: pp. 489-490]. In both cases, the navy officers were mavericks who brought about major technological improvements to the U.S. Navy. And in both cases, the main resistance to change was within the organization they sought to improve.

An indirect influence of atomic weapons brought about the revolutionary developments in rockets and missiles which are continuing today. It is in this arena that the relationship between warfare technology and national strategy becomes most intricately and confusingly expressed. Futhermore, the relationship though definitely established is different in form, content, and motivation depending on the governmental system where it exists.

The implications of guided missiles as nuclear weapons delivery vehicles was obvious to many people after the records of the German Rocket Team had been digested by the conquering nations. Having been the first operational cruise and ballistic missiles respectively, the German V-1 and V-2 were to be the progenitors of American and Soviet strategic and space launch systems.

The U.S. Navy developed its first nuclear strategic missile in the Regulus I, a subsonic cruise missile. First operational in 1953, the Regulus was designed to be launched from surfaced submarines. Although supersonic versions of Regulus were soon on the drawing boards, the vulnerability of the submarine which launched the missile was an unacceptable handicap. The Regulus program was curtailed within a few short years in order to fund the true fruits of technological convergence - the submarine launched Polaris Ballistic Missile.

4. Rockets and Ballistic Missiles

The study and research of rockets had been underway in Germany, Russia and the United States since early in the century. In 1929 Germany having been prohibited by the Treaty of Versailles from developing heavy artillery, turned to the science of rocketry for military weapons delivery. Aided by the genius of Wernher Von Braun and supported by substantial government funding, Germany's efforts to develop militarily useful, liquid fuel rockets began to produce major advances. Most notable among them was the V-2, the first ballistic missile.

The postwar transfer of expertise, records and equipment of the German Rocket Team to America and the U.S.S.R. helped speed the progress of both of the latters' rocket and missile programs. In the U.S. dozens of confiscated V-2's were assembled, studied and launched between 1946 and 1951. The V-2 design was incorporated extensively in the U.S. Viking and Redstone rockets. The navy conducted tests which included the launching of V-2's and Vikings from the decks of ships. The Navy's programs revolved around use of the rockets for high altitude atmospheric and weather research. Meanwhile the newly formed U.S. Air Force, as the agency most associated with long range nuclear warfare, embraced ICBM research enthusiastically. By 1955 the Atlas and Titan ICBM's were being developed, as well as the intermediate range ballistic missiles (IRBM), Jupiter and Thor [Ref. 30: pp. 128-129].

The proliferation of U.S. missile programs was generated by increasingly frequent reports of Soviet ICBM testing and development. Since each of the programs commanded a significant proportion of the defense budget and none of them were run by the Navy, senior officers of the sea service put for their own proposal for a ballistic missile in 1955. With four programs already in effect, a fifth was not desired and the Navy was left with the choice of joining Army or Air Force projects. The Navy chose to work with the Army to modify a liquid-fueled Jupiter for launching by ships or submarines. The joint effort lasted one year. [Ref. 56: pp. 7-8].

Several technology and military issues supported the Navy's decision to persist in its own missile program. First, all the existing programs including the Jupiter were liquid fuel rockets. Solid fuel system were much safer and easier to handle on a ship or submarine. Second modification of a Jupiter to solid fuel was more costly and less effective than a new missile would be [Ref. 35: p. 8]. Third, the obvious military advantage brought about by the success of the nuclear powered <u>Nautilus</u> made submarine basing the only logical choice for such an important weapon. Finally a solid fueled missile was smaller and less vulnerable to catastrophic failure than a liquid fuel missile. Faced with these considerations, the Eisenhower administration approved in December 1956, the Navy's request to begin the Polaris missile program.

5. Technological Perfection in Naval Warfare

The shocking news of Sputnik in October 1957, confirmed for the American public what intelligence reports had been already indicating: that the Soviets had shifted nuclear weapon delivery emphasis from manned aircraft to missiles. The U.S. Fleet Ballistic Missile (FBM) program was given more money and priority in the wake of the threat underscored by Sputnik. For the first time in their history, American homes were subject to the devastation of war. The first test firing of a Polaris from a submerged boat occurred, July 20, 1960. By the end of the year, two U.S. FBM submarines were on patrol, several more were under rapid construction. [Ref. 31: p. 9]

Although the Polaris system developed quickly, the Soviet Navy had successfully tested the concept of submarine launched ballistic missiles as early as September 1955. During 1955 to 1957, seven Soviet diesel boats were equipped with two tubes each for a surface launched SS-N-4 missile. The 300 mile range SS-N-4 was put on 23 "Golf" and nine "Hotel" class submarines in 1951 and 1962 respectively. By 1959, the Soviets had commissioned their first nuclear powered submarine and the direction of their sea based strategic forces was clear. [Ref. 34: pp. 37-38]

Since the early 1960's the FBM submarine in both the Soviet and U.S. navies have undergone significant technological improvements. Among the changes in the submarines are quieting, larger hulls, more speed, and more depth capability. The missiles have increased in size, number, range, and accuracy. The most important development in the modern submarine launched ballistic missile (SLBM), has been the multiple Independently-targeted Reentry Vehicle (MIRV) warheads. The MIRV system permitted the destruction of multiple targets from the same missile by dispensing several warheads in a predetermined pattern. Both the U.S. and U.S.S.R. have such systems operational. The nuclear powered ballistic missile submarine represents the technological peak of submarine development, possibly of naval warfare development. It possesses all the attributes desired in a decisive system. It has the endurance for which naval officers have sought for centuries. It is stealthy, but can move at nearly the speed of a modern surface combatant. The primary weapons consist of up to 24 MIRVed missles capable of depositing nuclear warheads on more than 100 targets at ranges over 5000 miles - and can do it within minutes. With one exception, the FBM submarine in operational mode is invulnerable to practically all conventional weapons and weapon delivery systems. The exception is the nuclear powered attack submarine.

Modern attack boats are technological perfection of the World Wars I and II submarines which nearly ruled the oceans. As with the FBM boats the nuclear propulsion systems gives it endurance limited only by that of the crews which operates it. The attack boat missions require more speed and greater maneuverability. These features are gained at the expense of quieting, but the price is small. A modern SSN uses torpedoes with speeds of more than 50 knots. Rocket assisted delivery systems can boost the range of the torpedoes to dozens of miles. Because of their effectiveness in the same environment as that of the FBM, the nuclear attack submarine is by far the former's most capable adversary.

Prior to the Cuban missile crisis in October 1962, the surface component of the Soviet Navy was nothing more than a coastal defense force. Since then, it has become like its submarine counterpart, a sophisticated and potent naval warfare asset. In particular, the development of anticarrier warfare (ACW) groups armed with cruise missiles and excellent antiaircraft gun and missile systems have decreased the viability of U.S. aircraft carriers. Carrying the roles of their surface ships even farther the Soviets have developed both carrier and non-carrier type capital ships during the 1970's and 1980's. For the U.S. Navy, technological evolution has led back to a path previously trod. That is the path of the cruise missile. Here again, the relationship between strategy and technology has created the need for change. Growth in quantity and quality of the Soviet surface fleet resulted in the development of belated successors to the Regulus. These missiles, the Harpoon and Tomahawk, in explosive power, propulsion, or guidance represent no significant breakthroughs in technology. Miniaturization has permitted their use in small platforms and engine efficiency has yielded long range form the relatively small missiles. However, these missiles are both subsonic and fly medium to low altitude flight profiles. Soviet cruise missile technology, possibly because it is not restrained by being subordinate to manned aircraft, has yielded both subsonic and supersonic missiles, with flight profiles covering very high to very low. In both the USSR and US navies the cruise missile has been integrated into submarine for submerged launch.

IX. THE IMPACT OF SPACE SYSTEMS

The progression of technology applied to naval warfare thus far discussed has the following six common areas of emphasis:

1. Expansion of the size of the area which a given naval force can keep under surveillance and control.

2. Increasing the endurance of a given naval force.

3. Reduction of force reaction and weapon delivery times.

4. Reduction of exposure of the force to hostile action.

5. Increasing the probability of kill per weapon.

In this section of the thesis it will be shown that space systems can contribute to all of these areas. However, inas much as the interface of space systems with terrestrial naval forces is potentially revolutionary in nature, non-standard approaches are necessary in order to realize the advantages fully.

A. EXPANSION OF THE AREA OF CONTROL

1. Terrestrial

The means of increasing area of surveillance and control have passed alternately through stages of adding force elements, extending the search and weapon range of individual units, or both. Gunpowder weapons were revolutionary in this respect, but remained the only development of such impact until the introduction and assimilation of steam propulsion. Airplanes and submarines extended the area into the three dimensional volume of present day naval warfare. In doing so, they created the need for defensive forces to widen their control dimensions by radar, sonar, torpedoes, and antiaircraft guns and missiles.

Machinery propulsion and aircraft provided their advantages through mobility and speed. Machinery freed the surface ship of its dependence on proper winds and weather and enabled a reliable maximum speed under most conditions. Forces could thus be employed in more regions and with greater confidence. Nelson's flagship at Trafalgar had guns with about a 600 yard range and in moderate breeze could make ten knots. Using a ten nautical mile visibility, the HMS Victory could survey 514 square miles in one hour but covered only 6.28 square miles with her cannon. One hundred years later, the steampowered Dreadnaught could make 21 knots easily, in most sea and weather conditions, and her guns were effective at ten miles. With ten mile visibility, the Dreadnaught could survey and strike anything within 734 square miles in an hour. For surface ships and guns subsequent improvements added perhaps twelve more knots of speed but increased gun range by a factor of two. The greatest improvement was in surface surveillance where radar permitted search at night and in conditions of fog, drizzle and smoke. When applied to fire control systems, gunnery action was extended in like manner.

Initially, airplanes expanded search area by virtue of a speed multiple of four over the fastest World War I ships. The altitude advantage also broadened the horizon by raising the height of eye. As a comparison, 100 feet was typical height of eye for an observer perched on the lookout platform of a World War I battleship. This yielded a horizon to horizon span of approximately 22 miles. An airplane of the same era, travelling at 2000 feet had a span of view stretching more than 100 miles. When height and speed of airplane are combined, the increase in search area is greater for the aerial observer by at least fifteen times. A more important change allowed by machinery was the development of submarines. They took naval warfare into a new dimension, greatly expanding the volume of space in which search and control needed to be exercised. Because early subs used only periscopes as their primary means of search, they were limited in their control capability.

Increase in underwater area control were made initially by longer torpedo ranges. However, in both world wars Germany used numerical strength to enlarge the area. Sonar was developed to give surface ships the ability to cross the interface between air and water for the conduct of underwater search. Technological evolution has led to drastic increases in capability particularly in passive detection. More recent advances in quieting have caused the detection pendulum to swing back towards the submarine. Airplanes used in the ASW role extended search area in the same manner as for surface surveillance, but were advantageous for other reasons as well.

The aircraft carrier put the advantages of the airborne platform in numbers large enough to change naval warfare significantly. In addition to the expansion of sea area which could be effectively controlled, the carrier gave naval forces the ability project power to inland targets.

As naval warfare expanded to three dimensions and individual platform capability improved, the area occupied by a force grew. Effective command and control of diverse and disparate units depended on communication from shore based headquarters to the fleet commander, and between the flagship and the dispersed members of the force. High frequency (HF) radio permitted long range command and control but was unreliable because of atmospheric effects.

2. <u>Space Systems and Expansion of Control</u>

a. Communications

It is in communications that space systems have had their most important and direct impact on U.S. naval forces. With an altitude of 22,300 miles, a geosynchronous satellite has one third of the earth's surface in view at all times. Consequently, three satellites provide the height of eye necessary to cover the entire Earth. From such an altitude the satellite provides an ideal antenna in that portion of the radio frequency spectrum (microwave) which penetrates the atmosphere without degradation of signal. The advantages offered by the use of line of sight microwave frequencies are:

- significantly improved signal reliability
- decrease in probability of signal intercept by hostile forces
- higher capacity of available spectrum
- increased jamming resistance
- high data rate

A translation of these advantages into expansion of area of control is fairly simple. Fast, reliable, and secure communications between force units stationed far apart permits their more effective coordination as a single entity. The technological improvements of platform sensor and weapon ranges are thus realized by allowing them to be sewn together through communications. Both offensive and defensive postures are thus improved.

The advent of nuclear weapons has so stressed the need for coordination such that only the microwave frequencies are capable of supporting it. In this, the means of reliable, fast communications to the distantly located upper levels of command, rely almost exclusively on satellites. Ironically the improved link between operating forces at sea and their shore based commanders has in some ways been a disadvantage. With availability, capacity, and reliability rates so high, the satellite links have ideally served the bureaucratic functions of naval administration. Thus, the broadening of control area exercise by headquarters has been extended to non-combat functions peculiar to peacetime. The explicit hazard is that non-combat functions become relatively more important, and the military posture of the unit, hence the force, suffers.

Along with the expansion of the area of naval force influence and the qualitative improvements in the means of control, the information available to units and commanders has grown. Technology has permitted this information to be transmitted by electronic means in digital form. Use of microwave communications links are much more capable of handing such information. Not only in the capacity greater, but rate of data transmission is much higher. Satellites provide the means to extend this advantage to dispersed formations as well as contribute information gathered from sources outside the force. All these advantages perpetuate the trend through history of expanding the area in which a given set of naval forces can effectively survey and control.

b. Surveillance

The extension of height of eye by satellites has been alluded to above. The first concrete indications of just how effective surveillance from spacecraft could be were provided in the U.S. Navy's early Viking program. When the

NRL fitted some of their rockets with cameras, the researchers got back photographs taken during the 100 mile high flight trajectory. Pieced together after developing, the photo mosaics covered land areas over 1000 miles in diameter in which natural and manmade features were clearly discernible. [Ref. 32: p. 466]

Since that time satellites equipped with photographic equipment have been used extensively by both the U.S. and the U.S.S.R.. Relatively short missions and frequency of coverage have kept photographic satellites in the reconnaissance roles instead of longer term surveillance. Their contributions to strategic intelligence and arms control verification are inestimable. More significantly, the contribution of photo satellites for the U.S. has been in the production of detailed maps of land areas as so that projection of force can be better extended to potential inland targets.

Wider use of the electromagnetic spectrum in naval warfare has provided counter detection sources especially vulnerable to detection by satellites. Electronic intelligence (ELINT) sensors can detect radio and radar emissions covering whole ocean areas. The Soviet Union has been especially active in this area with their ELINT ocean reconnaissance satellites (EORSATS). EORSATS provide valuable information on foreign naval forces including composition, location, capabilities and operations. Though satellite ELINT sensors capitalize on their access to large areas, their effectiveness depends on "cooperative targets", i.e. naval forces which have energized their electronic emitters. Proper emission control (EMCON) procedures, coupled with knowledge of when and where a force is vulnerable to collection, can defeat ELINT satellite efforts.

An obvious answer to the this limitation is an active sensor, radar, based in space. The U.S. Navy attempted such a capability with the Clipper Bow project. Clipper Bow was a research and development program geared toward the eventual production of ocean surveillance satellites having active radars. In spite of the overwhelming advantages of such a system the program foundered in 1979 amid interservice strife with the Air Force [Ref. 33: pp. 156-157]. The U.S. still is without an active radar ocean reconnaissance satellite (RORSAT) with no future capability in sight.

The Soviet Union has vigorously pursued RORSAT technologies having placed systems in operation since the early 1970's. Powered by small nuclear reactors, the Soviet RORSATS are used in tandem with EORSATS to more effectively detect and identify surface targets. Tying such a capability into naval forces for effective application of firepower has been accomplished by the Soviets. Information gathered by the reconnaissance satellite pairs can be downlinked to units equipped with appropriate equipment. Long range surface to surface missile platforms with such a capability thus have integrated their area surveillance and firepower means to gain expansion of the control of area.

Surveillance of the surface and air above ocean areas is a relatively direct matter compared to subsurface surveillance and control. In ASW, satellites contribute in many sublime and discrete ways. The remote oceanographic sensors on satellites provide information on weather, sea states, salimity, algae content and other environmental factors. When collated and processed the data can be used to take advantage of sonar paths both to detect foreign ones.

In summary space borne platforms are uniquely capable of many surveillance missions. The concept of active ocean radar surveillance systems, coupled with high speed processing of data has the potential to revolutionize naval warfare by making all large surface ships vulnerable to detection. Satellites, with increasing capability to influence the effectiveness of naval forces, will themselves likely become more important targets for hostile actions, truly revolutionizing warfare concepts of a more general nature.

B. SPACE SYSTEMS AND ENDURANCE

Space systems have little capability to affect the endurance of terrestrial naval platforms. It is in this sense that unorthodox views are necessary for the realization of revolutionary capability. The progress of space technology has made possible the reliance upon sensors place aboard satellites. Radar, electronic surveillance, infrared detection, and other sensors can be orbited for nearly indefinite periods depending upon altitude. Even as low as 300 miles, however, circular orbit provides a lifetime of over three years. Tradeoffs between power requirements of active sensors and distance from target are a primary consideration. The political and environmental restrictions on nuclear power systems will keep the U.S. from making significant progress in this direction. Consequently, the prospect of revolutionary change, capitalizing on the endurance of space borne active sensors will be the sole domain of the Soviet Union.

C. REDUCTION OF REACTION AND WEAPON DELIVERY TIMES

1. Terrestrial

This technological trend has been pushed from two converging lines. More traditionally the emphasis has been on faster platforms and weapons. Tactically, the prime example is the supersonic cruise missile. Strategically, the advantage has been conferred by submarine launched ballistic missiles.

The second line of convergence is the integration and use of real-time information. Served by digital data links which transmit information at the speed of light. Sensor platforms feed weapons systems with information usable for targeting.

By increasing information reliability and establishing appropriate threat priorities, integrated systems simply and shorten the decision making process. This decreases the time lag between target detection and weapon delivery. The process is the same for a multi-unit force as it is for an individual platform. The added wrinkle is the requirement to preclude mutual influence or attrition of friendly forces.

A non-technological means to reduce reaction time is forward basing of naval forces. Putting the assets close to likely theaters of action is expensive and politically risky, however. Aircraft carriers are a compromise of the two technological and one technological means. They use the speed of aircraft, the integration of supporting platforms and the logistical arenas to operate in theater. Their main vulnerabilities are to submarine attack and space borne surveillance.

2. Space Systems and Reduction of Reaction and Weapon Delivery Time

The reliance of modern naval communications on microwave frequencies has permitted the real time digital data links referred to above. However these links must be borne by satellites at ranges beyond the horizon. The technology and means of satellite communications are well developed and appear to have been assimilated by the fleet with litte resistance. The links and sensors which provide surveillance and targeting information will be limited in effect in their influence on reaction time until non-traditional weapons and ordnance delivery are introduced.

This leads to potentially the most revolutionary area of warfare technology and the most controversial. Space based weapon systems are specifically prohibited by the 1967 Outer Space Treaty signed by both the US and USSR, in January 1967. However in late 1967 the Soviets tested a capability later referred to as a "Fractional Orbital Bombardment System" or FOBS.

The FOBS tests involved the use of an SS-9 booster to extend the normal ballistic flight of an ICBM warhead, so that its trajectory through space was a portion of an elliptical orbit [Ref. 34: p. 99]. Essentially the concept could be extended in two ways. First a weapon circling the Earth could be deorbited, reducing the time between the attack signal and weapon impact by at least half. Second, is the development of a horizontal take-off single stage to orbit (HTO-SSTO) vehicle. The HTO-SSTO incorporates the technology of multi-cycle airbreathing engines, rocket propulsion, thermal protection and lifting body design [Ref. 35: p. IV-6]. With the ability to reach hypersonic speeds and orbit the HTO-SSTO combines capabilities to drastically reduce weapon delivery time.

Directed energy technologies with weapons applications are being intensively researched in both the U.S. and

U.S.S.R. These concepts involve lasers and particle beams. Although their destructive energies travel at the speed of light, their use against terrestrial targets does not appear feasible in the near future. Both types of directed energy are subject to severe attenuation or deflection in the atmosphere or Earth's magnetic field.

D. REDUCTION OF RISK AND EXPOSURE

1. Terrestrial Developments

Submarines and stand off weapons epitomize the technological products which reduce the exposure of the force to danger. The trend of increasing weapon ranges is as old as the cross-bow. However it is more than offensive weaponry. Small, fast ships or planes use their mobility and small target cross section to gain advantage. This was permitted by the development of efficient, compact propulsion systems. The same trend has converged with miniaturization of electronics to produce "smart weapons" with long range, keeping the launch platform at a safe distance.

Defensive measures have also received technological attention. Armor, radar directed antiaircraft guns, surface-to-air missiles are examples of extensive efforts to protect naval forces. The use of airplanes, viewed from a defensive perspective, can be seen as a means to keep the central section of a fleet out of harms way while simultaneously delivering weapons.

2. <u>Space Systems and Reduction of Risk and Exposure</u>

The advantage of space systems in reducing the risk to forces is no more apparent that the U-2 incident of May 1960. Although the reconnaissance plane was shot down by a Soviet missile and the overflights by U-2's thereafter ceased, the flights by Discoverer satellites served similar purposes [Ref. 30: p. 224]. No more U-2's were shot down because they did not have to be used in that role. Technology can provide similar protection of naval missions by satellites equipped with radar and other sensors. The concept of comprehensive satellite coverage, however, depends upon a dedicated system which can integrate, collate, and prioritize the information.

The use of stand-off weaponry in current inventory will not provide protection of which it is capable until a viable, accurate targeting system is available. The means to put such a system together exist. The NAVSTAR Global Positioning Satellite System (GPS) provides platforms with very accurate navigational information. Against non-mobile targets for which position information is accurately known (by photo reconnaissance satellites?), long range weapons can be adequately programmed for attack. Mobile targets however, will require updates of information to the weapon during flight. Using the accurate navigation information of GPS, and a space based sensor such as active radar, the target information can be sensed, translated to a coordinate system, and transmitted to the enroute missile. The missile can sense its own position by GPS input, compare with the remote sensor information about the target, and then make in flight corrections. In essence this capability makes the missile a remotely piloted vehicle (RPV). The force which launched the weapon can stay away from the missile target area by nearly the maximum range of the missile.

Other types of remote sensing are possible in the ASW mission. Current research is being conducted with blue-green lasers that seem capable of penetrating at least partially to submarine operating depths [Ref. 33: p. 190]. Remembering that the span of time between the introduction of radio and radar systems was barely 30 years, it seems likely that if blue-green lasers can be used for communications, their next use as submarine detection or localization systems cannot be far off.

E. INCREASING THE PROBABILITY OF KILL PER WEAPON

1. Terrestrial Developments

In the progression of naval warfare developments, the predominant trend of technology has been to improve probability of kill (P_k) per weapon. Destructive power alone however, is not the only requirement for progress. Well after gunpowder and cannon were introduced the tactics of ramming and boarding were the most effective means of naval warfare. With the possible exception of nuclear weapons, the weapons development process has been evolutionary. New means of depositing energy on target take a long period of time for their assimilation and the generation of tactics which enhance their use. Even after the weapon itself has been in existence for awhile new tactics can permit the realization of potential not previously used. Such a situation occurred in the battle of Les Saintes in 1782. Though the cannon used in the battle had been in existence for a century and a half, the breaking of the French line of battle by the British commander so confused the French that they could not effectively respond to the maneuver and were routed. The victory, as was the case in so many British naval actions, was due to superior use of weapons which were not themselves superior.

Constant aim gunfire, the gyroscopic controlled torpedo, VT fuze, and the expanding rod surface to air missile warhead are examples of technological improvements to gain higher kill probabilities. In some cases the increase in P_k was due to a new technology (VT fuze), in others it was an older or simpler concept used in a new manner such as the Gatling Gun used in the Vulcan Phalanx Close-In Weapon System.

Nuclear weapons as with the increasing size of naval gun projectiles and conventional bombs, gain in P_k primarily from their sheer destructive power. In many cases however, such indiscriminate destruction does not yield the attainment of the military objective. The neutron weapon of the late 1970's had a destructive capacity of one kiloton but was twice as effective against tank crews as a ten kiloton, straight fission weapon.

2. Space System Contributions to higher P_ks

The U.S. Navy's Vanguard program provided confirmation that the Earth was pear-shaped rather than perfectly round. The geodetic data was used in the development of ICBM flight parameters to improve missile accuracy. Similarly, the Transit navigation satellite system permitted Polaris equipped submarines to fix their positions quickly and accurately and thus improved the Polaris missile accuracy on launch. Although these strategic applications of space systems are some of the most prominent examples, higher P_k of tactical systems can result from more effective use of satellite systems.

Tactical surprise can raise weapon P_k by allowing weapon penetration into unprepared targets. Through EMCON strict ocean transits supported by GPS navigation, and fully integrated tactical intelligence support, strike operations can multiply their hits on target many times over. In addition to navigation and weather information space based sensors such as crosslinked radar and ELINT satellites could form the eyes and ears of a battle group attempting to remain undetected and get to a weapons launch point.

Another use of space systems to gain higher weapon kill probabilities and decreased personnel risk would be in the remote operation of an RPV equipped with television and data links from a merchant type vessel or submerged submarine. The data and image links would go from RPV to satellite for conversion to EHF or blue green laser for downlink to the controlling unit. Used this way the RPV could probe defenses or conduct reconnaissance prior to a strike without compromising the location of the controller. A satellite with properly developed sensors could pick up the signature of a wake homing torpedo in order to alert the target as well as to locate the torpedo's origin. Through on board processing and previously established links with the satellite, immediate course, speed, and relative position of the torpedo could be made available to the ships or submarine getting the support.

X. CONCLUSIONS

The technological development of naval warfare has for the most part been a series of evolutionary changes. Revolutionary developments, though occurring, have come usually in peacetime, with the successful adaptation of change coming through the experience of combat when the motivation and resources for its use are readily available.

New technology alone is no guarantee of progress, nor is it a prerequisite for improved combat effectiveness. In the past four decades, however, the rate of technological change appears to be increasing. The primary direction of change for naval warfare technology is in systems integration and space systems. The two are related because of the dispersed nature of modern naval forces and the pivotal role of communications in the integration and coordination of both tactical and strategic missions.

Space borne systems are potentially revolutionary in their impact on naval warfare. The Soviet Union appears to be capitalizing on space systems to consolidate their naval build up of the past quarter of a century. Similar to patterns of the French Navy in the seventeenth and eighteenth centuries, when innovation and change were sought to compensate for British naval supremacy, the Soviet Navy has freely incorporated new means and concepts. The primary avenue for change is in space where they have apparently integrated both active and passive sensors into potential targeting systems for long range weapons.

Although the imagined characteristics and means of future conflict are widely varied, space systems for whoever employs them, can make significant contributions to the effectiveness of naval forces. Among the general areas of improvement are increases in search area, increased kill probability for weapons, reduction of weapon delivery time, reduced risk of exposure to hostile forces, and increased endurance of forces. These areas also represent the trends of progress contributed by naval warfare technology throughout history.

Today's threat cannot be ignored while preparing for tomorrow's war. National and military strategy must somehow account for both. Space systems and naval warfare are closely related because employment of the former enhances the ability to conduct the latter. However, they are also related because they represent the transition of primacy in importance to national security from one arena to the next.

XI. RECOMMENDATIONS

Based on the trends discussed above the following recommendations are made.

1. Promote commercial interest in space. In three previous important changes, commercial involvement signalled military value ahead of assimilation by navies. These changes were the development of ocean going sailing ships, the use of steam propulsion, and development of aircraft. This is particularly important in a democratic country with a capitalistic economy. Commercial investment could result in increased access as well as expansion of a supporting industrial technology base.

2. Develop, build and operate space based radar (SBR) and other associated sensor systems as a top priority. The transition to space borne sensor systems, particularly SBR, is the next logical step in the evolution of naval warfare sensor technology. Expansion of the naval force area of control was mentioned as a trend to which technology has contributed. The potential field of view available to an orbiting platform represents the obvious continuation of that trend. Furthermore, the satellite based sensor is an enhancement of the trends toward increased endurance of naval forces and reduction of exposure to hostile fire.

   The Earth orbiting platform has a lifetime ranging from weeks to indefinite--much longer in duration than the on-station endurance of any terrestrial systems. As an unmanned platform, SBR follows the evolutionary path toward reduced exposure of the force. While providing an important surveillance capability, the SBR is far removed from the units which use its information. Thus, even though the orbiting sensor may be a priority target, destroying it would not damage the force on the force's firepower.

3. Emphasize the tactical and strategic integration of intelligence and other information into more readily usable targeting data. Couple the transmission of such data to munitions which make use of GPS navigation fixes for correctable trajectories and flight paths.

The U.S. Navy already has weapon systems which can carry warheads hundreds of miles. Whether in the form of airplanes or missiles, such a capability is surely an expansion of the force area of control. But the realization of the full potential of these weapons has not been achieved. Manned aircraft expand the control area and reduce weapon delivery times--both of which are consistent with trends mentioned above. To some degree they have reduced the risk to the force. Recently however, planes themselves have become increasingly vulnerable even though they are a primary offensive arm. Guided missiles offer the same advantages as manned aircraft. In addition, they serve to reduce the exposure of the force by being unmanned and relatively invulnerable compared to manned aircraft. The full benefits of over-the-horizon (OTH) guided weapons can only be achieved through the precise navigation and targeting data provided by space systems. The surveillance, targeting, navigation to target, and communication of enroute control commands, are all accomplishable through space systems and can be done over maximum weapons ranges at less risk to the force than if provided by terrestrial systems.

4. Gradually deemphasize surface ships including aircraft carriers and large, complex combatants. This does not mean to take their levels to zero, however. In their place, increase numbers of submarines, space sensors and mining capability. This recommendation implies more than a simple acknowledgement that fiscal limitations preclude the expansion of land, air, and sea forces, and the simultaneous expansion of space capability. Increased emphasis on space must come at the expense of some other capabilities. Before that can happen however, the slow, fundamental shift in the relative importance of space and terrestrial air and surface military systems must be recognized. The trends in naval warfare technology lead in directions which indicate that space systems, along with submarines, and mine warfare, are the most viable means of naval force employment.

5. Work ambitiously to centralize command, control and strategic direction of all U.S. armed forces. The goals should be increased accessibility to space, broadening of space capability, and increased responsiveness of space system support under a comprehensive national military strategy. Although this recommendation could be the subject of a thesis on its own merits, the point is simple. Costs of space systems will require to United States to more closely specify, control, and coordinate its military space

programs. Beyond cost however, is the basic recognition that, by their nature, space platforms cross all traditional earth boundaries. Consequently effective space system use is contradicted by fragmentary management and the service-specific mission orientation which has been used in terrestrial military programs. Stronger, more centralized control of the U.S. military space program is necessary in order to make the transitions in naval warfare from the traditional means to the future.

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